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Applicant:	Amachai HEINES, et al.
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Art Unit:	Not Yet Assigned
Examiner:	Not Yet Assigned

Honorable Commissioner of Patents and Trademarks
Washington DC 20231

LETTER ACCOMPANYING NATIONAL STAGE FILING

Sir:

Further to the concurrent filing of the U.S. National stage of PCT/IL99/00488 applicants bring US Patent application 09/623,592, which is the US national filing of PCT/IL99/00130 to the attention of the patent office. Applicants submit that it would be more efficient to have the same examiner handle both of these cases. In particular, it would be most efficient if Examiner Blackman, who examined PCT/IL99/00488 were to examine both cases in the national stage.

These two applications have identical first claims. PCT/IL99/00130 was prosecuted with the EPO as the searching and examining authority. PCT/IL99/00488 was prosecuted with the USPTO as the searching and examining authority. In the IPERs issued in both cases, claim 1 was found to be patentable, although different art was cited. In the EPO examined case claims 1-70 (all dependent on claim 1) were found to be patentable and claims 71-74 were found to be obvious. In the US case (in which there were a number of independent claims and in which the dependent claims different from those in the EPO case) all 70 claims were found to be patentable.

Respectfully submitted,
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MICRO-MECHANICAL FLAT PANEL DISPLAY WITH TOUCH SENSITIVE INPUT AND VIBRATION SOURCE

RELATED APPLICATIONS

This application is a continuation-in-part of PCT application serial number PCT/IL99/00130, which designates the US, the disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

The invention relates to visual display systems and in particular to flat-panel displays produced using micro-machining techniques

BACKGROUND OF THE INVENTION

Flat-panel video displays are ubiquitous components of many consumer, industrial and military products and devices. They are found in computer laptops, automobile dashboards, microwave ovens and a myriad of other machines and devices with which man interacts.

Active-matrix liquid-crystal displays dominate the market for high quality high-resolution flat-panel displays. However, these displays are relatively expensive and the amount of power they consume when operating is relatively large in comparison to the amount of power readily available from many battery driven devices.

The need and desire to incorporate visual displays into more and more products, ranging from portable GPS receivers to toys, has created a strong demand and expanding market for inexpensive flat-panel displays that can provide high quality images and operate with low power consumption.

In response to the demand, new types of flat panel displays have been developed based on the processing of silicon using MEMS technology. MEMS technology enables microstructures having features on the order of a few microns to be formed on appropriate silicon substrates. The technology can therefore be used to produce "pixel" sized devices, on silicon, that can manipulate light. Arrays of these devices are useable to form flat-panel displays that are potentially inexpensive, that operate with low energy consumption and provide high-quality images.

Most flat-panel displays produced using silicon technology belong to one of two general types. A flat-panel display of a first type has pixels each of which comprises a liquid crystal cell formed on a silicon substrate. Light, which may be ambient light or light from an appropriate light source, illuminates the pixels. Transmittance of the liquid crystal in each pixel for the light determines how bright the pixel appears. The transmittance of the liquid crystal is controlled by voltage on electrodes in the pixel. A pattern of pixels having varying levels of brightness is formed on the display to produce an image by controlling the voltage on the

electrodes in each pixel of the display. Images provided by this type of display generally suffer from low brightness and low contrast.

A flat panel display, hereinafter referred to as a "micro-mechanical display", of a second type, has pixels each of which comprises at least one movable structure micro-machined on a silicon substrate. The position of the at least one moveable structure in each pixel controls how bright the pixel appears by controlling an amount of light that the pixel reflects or diffracts. Generally, the position of the at least one moveable element is controlled by electrostatic forces between the at least one moveable element and electrodes in the pixel that are generated by applying appropriate voltages to the electrodes. Often the voltages are relatively high and moving the at least one moveable element requires a relatively large expenditure of energy. Usually, in these types of displays, brightness and image contrast are dependent upon viewing angle, as measured with respect to the normal to the plane of the display, and decrease as the viewing angle increases. Some of these displays require an internal light source that consumes relatively large amounts of power when operating.

A micro-mechanical display in which the at least one moveable structure in pixels in the display comprises a plurality of parallel flexible reflecting ribbons is described in US Patent 5,841,579 to D. M. Bloom et al, which is incorporated herein by reference. The flexible ribbons in a pixel of the display are normally located parallel to the plane of the substrate on which the pixel is formed at a small distance above the plane. The ribbons are controllable to be depressed towards the substrate by electrostatic forces that are generated by voltages applied to electrodes in the pixel.

To form an image on the display, the pixels in the display are illuminated with light from a suitable light source so that light is incident on the pixels at a given angle with respect to the plane of the display. When alternate ribbons of the plurality of ribbons in a pixel are depressed, the plurality of ribbons in the pixel form a diffraction grating that diffracts some of the incident light at an angle such that the pixel appears bright to a user of the display. If alternate ribbons are not depressed, the plurality of ribbons in the pixel reflect the incident light at a different angle such that light from the pixel does not reach the eye of the user and the pixel appears dark. An appropriate pattern of bright and dark pixels forms the image on the display. The patent describes methods for using pixels of the type described to produce a flat-panel displays that provide color images.

Another type of micro-mechanical display is described in US patent 5,636,052 to S.C. Arney et al, which is incorporated herein by reference. In this flat-panel display the at least one moveable element in a pixel is a membrane. The membrane is flexibly supported so that it is

parallel to the substrate with a small air gap between the two. Light that is incident on the pixel is reflected by both the substrate and the membrane. The height of the air gap determines whether the reflected light from the membrane and the substrate interfere constructively or destructively and therefore if the pixel appears bright or dark respectively. An addressable electrode in the pixel, when charged attracts the membrane towards the substrate thereby controlling the height of the air gap and therefore whether the pixel is bright or dark. In order to displace the membrane, relatively high voltages, on the order of tens of volts, must be applied to the addressable electrode.

The use of some micromechanical devices presents a stiction phenomena. Various methods of reducing or counteracting stiction in micromechanical devices are described, for example, in "Adhesion of Polysilicon Microbeams in Controlled Humidity Ambients", by M.P. de Boer, et al., Mat. Res. Soc. Symp Proc., Vol. 518, pp. 131-136, 'Stiction in Surface Micromachining", Niels Tas, et al., J. Micromech. Microeng., 6 (1996) pp. 385-397, US Patent 5,867,202 to Knipe et al., US Patent 5,447,600 to Webb, US Patent 5,768,007 to Knipe et al., "Piezoelectric Micromotors for Microrobots", by Anita Flynn et al., Journal of Micromechanical Systems, Vol. 1, No. 1, March 1992, "Electrostatic Comb Drive Levitation and Control Method", by William C. Tang, et al., Journal of Micromechanical Systems, Vol. 1, No. 4, December 1992, and a book "High Voltage Devices and Circuits in Standard CMOS Technologies", by Hussein Ballan and Michel Declercq, ISBN 079238234X, by Kluwer Academic Publishers, November 1998, the disclosures of which are incorporated herein by reference.

It would be advantageous to have a flat panel display that uses ambient light, without the need for a separate light source, and that can provide high quality high contrast images while operating at low voltages with low power consumption.

SUMMARY OF THE INVENTION

An aspect of some preferred embodiments of the present invention is related to providing a micro-mechanical flat-panel display that uses ambient light and provides high-contrast images at substantially all viewing angles with respect to the plane of the display

An aspect of some preferred embodiments of the present invention is related to providing a flat-panel display that operates with low power consumption.

An aspect of some preferred embodiments of the present invention is related to providing a flat-panel display that operates using electrical power supplied at low voltages, such as 5 volts or less. In some embodiments of the invention, a high voltage is used, such as

50 volts. Optionally, the device uses a combination of high and low voltages, in which the addressing uses low voltages and the pixel flipping uses high voltages.

An aspect of some preferred embodiments of the present invention relates to providing a flat-panel display that provides black and white and/or gray level images.

An aspect of some preferred embodiments of the present invention relates to providing a flat-panel display that provides color images.

An aspect of some preferred embodiments of the present invention relates to providing a micro-mechanical flat-panel display formed on a substrate and having pixels that comprise a moveable element.

In a preferred embodiment of the invention, the moveable element is formed in the shape of a thin planar panel having first and second relatively large face surfaces and thin edges. The panel, hereinafter referred to as a "flipper", is hinged to the substrate in such a way that it is rotatable from one to the other of two limiting positions about an axis of rotation that is parallel to the surface of the substrate. The limiting positions are hereinafter referred to as "on" and "off" positions. The flipper is preferably at least partly formed from a conducting material.

In the on position the first face surface faces a user looking at the display and is visible to the user. The second face surface of the flipper faces the substrate, facing away from the user, and is not visible to the user. In the off position the second face surface faces the user and is visible to the user while the first face surface faces the substrate. Preferably, in the on and off positions, the plane of the flipper is close to and substantially parallel to the surface of the substrate. Preferably, the flipper rotates through approximately 180^{o} about the axis of rotation to rotate between on and off positions.

According to an aspect of some preferred embodiments of the present invention, rotation of the flipper is controllable so that the flipper is bistable. The flipper is either in the on position or in the off position and remains in one position until it is controlled to rotate to the other position. When the flipper is either in the on or off position the pixel consumes little or substantially no energy.

An aspect of some preferred embodiments of the present invention relates to providing addressable electrodes for each pixel in the substrate to which voltages are applied in different configurations so as to control rotation of the pixel's flipper. For some voltage configurations applied to the electrodes, electrostatic forces generated between the flipper and the electrodes prevent the flipper from rotating between on and off positions. In these voltage configurations,

substantially no current flows in the pixel and therefore the pixel consumes little or no energy. In other voltage configurations, electrostatic forces between the flipper and the electrodes generate a torque that rotates the flipper from one to the other of the on and off positions.

According to another aspect of some preferred embodiments of the present invention, the first face surface of the flipper in a pixel has a first color and the second face surface of the flipper has a second color. In addition, substantially all surfaces in the pixel that are visible when the flipper is in the on position, in which position the first face surface of the flipper is visible, are colored to have the same color as the first face surface of the flipper. Similarly, substantially all surfaces in the pixel that are visible when the flipper is in the off position, in which position the second face surface of the flipper is visible, are colored to have the same color as the second face surface of the flipper. As a result when the flipper is in the on position the pixel appears to have the first color and when the flipper is in the off position the pixel appears to have the second color.

In some preferred embodiments of the present invention the first color is white and the second color is black. In these preferred embodiments of the present invention pixels in the display are white when the flipper is in the on position and black when the flipper is in the off position and the display provides black and white images.

In some preferred embodiments of the present invention in which the first color is white and the second color is black, gray level images are provided. A gray level for a pixel is achieved, in accordance with a preferred embodiment of the present invention, by switching the pixel's flipper between on and off positions so rapidly that the brain does not discern that the pixel is either black or white. Instead the brain perceives that the pixel is gray. The gray level perceived is determined by the ratio between the times that the flipper is in the on position and the off position.

In some preferred embodiments of the present invention gray level images are achieved by grouping pixels in a flat panel display into "super-pixels". A super pixel comprises a plurality of pixels, for example three pixels, each of which is contiguous with at least one other pixel in the super pixel. A super pixel is small enough so that the eye does not distinguish whether a single pixel in the super pixel is black or white. Instead the eye integrates the stimuli received form the pixels in the super pixel and perceives an average of the received stimuli which is a gray level. For example, a super pixel with three black and white pixels can provide four gray levels of luminance. The constituent pixels may be the same (visual) size or may be of different sizes. In one example, the pixels in a group are of sizes x, x*2 .. $x*2^{(n-1)}$, with n

the number of pixels, so that 2^n-1 different gray level can be achieved. Alternatively, non-binary relations between pixels sizes are used, for example, the sizes having ratios of powers of three.

In other preferred embodiments of the present invention the first color of pixels in a super pixel is red (R), green (G) or blue (B) and the second color is black. Pixels in the super pixel are therefore R, G or B when their flipper is in an on position and black when their flipper is in an off position. Super pixels comprising "color" pixels are useable, in accordance with a preferred embodiment of the present invention to provide a color flat-panel display.

An aspect of some preferred embodiments of the present invention relates to providing a pixel, hereinafter referred to as a "multi-flipper pixel" that comprises at least two flippers. The axes about which flippers rotate between on and off positions are congruent or parallel and close to each other. The flippers are flipped back and forth between on and off positions and lie on each other in much the same way that pages in a book are flipped back and forth and lie on each other when the book is lying open on a table.

An issue addressed by some preferred embodiments of the invention is the reduction or counteracting of stiction between a flipper and the substrate.

An aspect of some preferred embodiments of the invention relates to overcoming stiction in a planar-electrode device using a levitation electrode. In a preferred embodiment of the invention, the levitation electrode is raised higher than a movable element whose stiction is to be broken. However, in some embodiments, the electrode may be the same height or even slightly lower, and still generate a net levitating force on the movable element, to break its stiction and levitate the element over the surface of the device. In a preferred embodiment of the invention, additionally to the planer electrodes used to move a moving part of the device, such as a flipper, by 180° flipping, a levitation electrode is provided substantially perpendicular to the planer electrode and/or the moving part. Preferably, voltage is applied to the levitation electrode at least at the start of motion of the moving part in order to free it of the stiction. In an exemplary embodiment, the device is a flipper pixel as described herein and the levitation electrode comprises one or more electrodes which extend in a direction perpendicular to the substrate.

An aspect of some preferred embodiments of the invention relates to various nub geometries. Preferably, but not necessarily, the nub geometries are selected such that they reduce stiction between the nubs and a moving element in contact with them. In a preferred embodiment of the invention, the tip of the nub is formed to have a reduced contact area with

the moving element, for example the tip being pitted (having one or more pits), pointed, rounded and/or roughened. Alternatively or additionally, a face of the moving element and/or its contact point on the substrate may be pitted and/or roughened, to reduce contact area.

An aspect of some preferred embodiments of the invention relates to locating the nubs at locations where the forces applied to move the moving element will have a greater leverage and/or more suitable angle to oppose the stiction. In one example, the nubs are formed near a rotation axis of the moving element, so that forces acting at the middle or end of the moving object will provide increased leverage. Alternatively, the nubs are distributed in a non-symmetric manner relative to the applied force, so that the applied force will exert torsion, shearing and/or tearing forces on the adhered region (usually a nub), in desired directions to break the stiction forces.

An aspect of some preferred embodiments of the invention relates to using a stiction reduction coating, for a flipper-pixel devices as described above. In a preferred embodiment of the invention, the stiction reducing coating is applied to the nubs, to reduce stiction of the flipper to them. Alternatively or additionally, the coating is applied to the flipper and/or to parts of the substrate, other than the nubs. Optionally, the stiction-reducing coating also functions as a light modifying material. In one embodiment of the invention, the coating selectively reflects or absorbs light. Alternatively or additionally, the coating selectively reflects a certain wavelength of light. Alternatively or additionally, the coating selectively polarizes light. These selective attributes of the coating may be achieved via chemical or physical means. For example in a low stress silicon nitride coating, the thickness of the coating determines if it reflects or absorbs light. Alternatively, different coating materials or additives may be used for different effects. Optionally, the insulating layer is deposited only under the nubs.

An aspect of some preferred embodiments of the invention relates to providing a force that acts to reduce the effect of stiction that couples a flipper and a surface the flipper is in contact with. In one preferred embodiment, the force is provided using a spring which is compressed or tensed when the flipper is in contact with the substrate. The force applied by the spring may be designed to be in one or more of many directions, including, for example, in the direction of the movement of the flipper or perpendicular to the flipper movement. In a preferred embodiment of the invention, the spring is integrated with the flipper at one or more ends thereof, so that when the flipper is activated (e.g., by varying an electric field vector), the spring is tensioned. Preferably, the flipper is activated by first attracting it to the substrate, storing energy in the spring. When a flipping signal is applied, the field resulting from the signal flips the flipper in conjunction with the release of the energy pent up in the spring.

Preferably, the spring is coplanar with the flipper, rather than protruding from it, however, this is not essential. Alternatively or additionally, the spring is formed of an insulating and/or low stiction material, however, this too is not essential. Alternatively or additionally to a separate spring, the flipper itself may function as a spring, which is bent by the stiction effects and/or electrostatic effects. Alternatively, the spring may be formed on the substrate, for example by undercutting a nub.

An aspect of some preferred embodiments of the invention relates to using vibration to counteract stiction effects in a flipper-pixel device. The vibrations may be generated in one or more of many ways, including for example, by providing actively vibrating elements and/or by activating a part of the device in a repeating manner, to cause vibration. In one example, a local ultrasonic vibrator (local to the pixel and/or a small group of nearby pixels) is used to provide the vibration. Such a vibrator may be coupled and/or located adjacent to a nub and/or a hinge. Alternatively or additionally, a vibrator is provided to vibrate the entire display device. Such a vibrator may be situated, for example at the edge of the device. Possibly, a propagating wave is used, which propagates from the edge of the device to the flipper area. A preferred method of generating vibrations is by electrifying electrodes on a piezoelectric material, such as PZT. Alternatively, the device may have a vibrating element laid under it. In another example, the vibration is caused by activating the flipper element, for example with an AC voltage, to cause vibration. Alternatively, other pulse forms, such as a non-symmetric saw-tooth pulse form, may be used. In a preferred embodiment of the invention, the frequencies used match natural resonance frequencies of the flipper and/or the nub. Optionally, the nub is designed to concentrate the energy of the vibration, so that an increased amplitude is provided. For example, the nub may be horn shaped, so that the amplitude of vibration of its tip is greater than of its base. Preferably, but not necessarily, the application of vibration is synchronized with the application of a flipping voltage to flip the flipper.

An aspect of some preferred embodiments of the invention relates to integrating a micro-machined flipper based display device and a touch input device. In a preferred embodiment of the invention, a transparent surface is displaced from the substrate by a plurality of support elements. Preferably, these support elements provide a touch-sensitive functionality. In one example, coupled to some or all of these support elements are pressure sensors which generate a charge, generate a voltage and/or change their resistance or other electrical properties when pressure is applied to the support element. Alternatively or additionally, a capacitance based touch device is provided in which changes in capacitance at locations of the display are sensed using a plurality of electrical circuits, which circuits are

possibly not coupled to support elements. Alternatively, a non-local touch-input device technologies is used, for example a Surface Acoustic Wave (SAW) based input (using detection circuitry at the periphery of the device). In some embodiments, at least some of the support elements are made flexible (e.g., by suitable selection of material) and/or are spaced from the touch surface so that various types of contact of objects with the surface will affect the propagation of ultrasonic waves in the display surface. Exemplary spacing of the support elements are fewer than 1:10, 1:20 or 1:50 elements per pixel, in the horizontal and vertical axes of the display.

An aspect of some preferred embodiments of the invention relates to methods of electrifying the individual pixel elements. In a preferred embodiment of the invention, circuitry at the periphery of a display device incorporating the pixels is used to send instructions to the pixels, while circuitry associated with individual pixels is used to activate the pixel. Thus, data can be written to the pixels at a higher rate and the pixel can maintain its electrical condition for a duration required for flipping. Alternatively or additionally, lower power can be used for data transmission, while the pixel circuitry can amplify the received data to power the pixel. In a particular type of amplification, transistors are used as switches to channel power to flipping electrodes. In a preferred embodiment of the invention, the use of switches negates the need for complementary transistors. Preferably, the switch transistors are maintained in an on state by a capacitor charged during a pixel addressing operation. Thus, even after the addressing of a pixel is completed, the capacitor can maintain the switch in an energy channeling state. One possible advantageous result, especially if high voltage is used for flipping, is that high flipping rates are possible, allowing the emulation of gray-levels by rapid flipping and/or allowing higher spatial resolution with relatively simple circuitry.

In one embodiment of the invention, flip-chip bonding methods, or their equivalents, are used to bond one or more integrated circuits to the periphery of the display device, to control individual or groups of pixels. Alternatively or additionally, aluminum on glass technology is used to form the pixels. Alternatively, a silicon wafer having a plurality of control circuits formed thereon is bonded to the periphery of the display device. Alternatively or additionally, thin film transistors or other types of transistors may be deposited under the flippers. In one example, the flippers are made using aluminum on glass technology and the transistors are deposited on the glass before the aluminum.

There is thus provided in accordance with a preferred embodiment of the invention, a visual display comprising a plurality of pixels each of which comprises:

a surface having an area less than 1 square millimeter comprising first and second regions having surface finishes; and

a thin planar panel having first and second sides having surface finishes, wherein said panel is rotatably coupled to said surface so as to rotate between a first and a second position about an axis parallel to said surface, which axis defines a hinge;

wherein said panel in said first position is positioned over said first region with its second side facing said first region and wherein in said second position said panel is positioned over said second region with its first side facing said second region. Preferably, said panel defines an angle between said first position and said second position and where said angle is over 135°. Preferably, said angle is over 160°. Alternatively or additionally, said angle is over 180°. Alternatively or additionally, said angle is over 190°.

In a preferred embodiment of the invention, said angle is under 270°.

In a preferred embodiment of the invention, said panel is in contact with said first region while in said first position. Preferably, said contact causes stiction between said panel and said region. Alternatively or additionally, the display comprises at least one nub between said panel and said region. Preferably, said nub is formed on said panel. Alternatively, said nub is formed on said region.

In a preferred embodiment of the invention, said at least one nub is nearer said hinge than an outer edge of said panel. Alternatively or additionally, said panel contacts both said nub and said region. Alternatively or additionally, said nub has a tip having a cross-section smaller than another cross-section of said nub. Alternatively or additionally, said nub has a rounded tip. Alternatively or additionally, said nub has a pitted tip. Alternatively or additionally, said nub has a roughened tip. Alternatively or additionally, said nub is coated with a stiction reducing coating. Preferably, said coating comprises an insulator. Alternatively, said coating comprises Silicon Nitride.

In a preferred embodiment of the invention, the display comprises a vibration source underlying said nub or said hinge. Preferably, said vibration source comprises a piezoelectric material.

In a preferred embodiment of the invention, the display comprises a layer of insulating material between said plane and said first region.

There is also provided in accordance with a preferred embodiment of the invention, a visual display comprising a plurality of pixels each of which comprises:

a surface comprising first and second regions having surface finishes;

a thin planar panel having first and second sides having surface finishes, wherein said panel is rotatably coupled to said surface so as to rotate between a first and a second position about an axis parallel to said surface, which axis defines a hinge; and

a layer of insulating material between said plane and said first region.

wherein said panel in said first position is positioned over said first region with its second side facing said first region and wherein in said second position said panel is positioned over said second region with its first side facing said second region. Preferably, said layer doubles as a colorant. Preferably, said color properties are determined by a thickness of said layer. Preferably said material comprises Silicon Nitride. Alternatively or additionally, said pixel is manufactured using Aluminum on Glass technology.

In a preferred embodiment of the invention, said pixel comprises at least one flipping electrode for flipping said panel between said two positions.

There is also provided in accordance with a preferred embodiment of the invention, a visual display comprising a plurality of pixels each of which comprises:

a surface comprising first and second regions having surface finishes; and

a thin planar panel having first and second sides having surface finishes, wherein said panel is rotatably coupled to said surface so as to rotate between a first and a second position about an axis parallel to said surface, which axis defines a hinge;

wherein said panel in said first position is positioned over said first region with its second side facing said first region and wherein in said second position said panel is positioned over said second region with its first side facing said second region; and

wherein said pixel comprises at least one flipping electrode for flipping said panel between said two positions. Preferably, the display comprises at least one levitation electrode for moving said panel, thereby aiding said flipping electrode in said flipping out of said first position. Alternatively or additionally, the display comprises at least one levitation electrode for aiding said flipping electrode in said flipping. Alternatively or additionally, said at least one levitation electrode inhibits said flipping. Alternatively or additionally, said at least one levitation electrode protrudes above said first region. Alternatively or additionally, a same levitation electrode aids flipping both back and forth. Alternatively or additionally, said at least one levitation electrode is shared between at least two of said pixels. Alternatively or additionally, said at least one levitation electrode comprises at least two levitation electrodes each one associated with a different pixel and electrified together. Alternatively or additionally, the display comprises circuitry for electrifying said at least one levitation electrode in synchrony with the flipping of a particular pixel. Preferably, said levitation electrode is

electrified prior to electrifying said flipping electrode. Alternatively, said levitation electrode is electrified simultaneously with electrifying said flipping electrode.

In a preferred embodiment of the invention, said panel comprises at least one spring attached thereto, which spring couples said panel and said first region when said panel is at said first position.

There is also provided in accordance with a preferred embodiment of the invention, a visual display comprising a plurality of pixels each of which comprises:

a surface comprising first and second regions having surface finishes; and

a thin planar panel having first and second sides having surface finishes, wherein said panel is rotatably coupled to said surface so as to rotate between a first and a second position about an axis parallel to said surface, which axis defines a hinge;

wherein said panel in said first position is positioned over said first region with its second side facing said first region and wherein in said second position said panel is positioned over said second region with its first side facing said second region; and

wherein said panel comprises at least one spring attached thereto, which spring couples said panel and said first region when said panel is at said first position. Preferably, said at least one spring is an extension of a sheath portion of said panel, opposite said hinge area.

In a preferred embodiment of the invention, said display comprises at least one vibration source.

There is also provided in accordance with a preferred embodiment of the invention, a visual display comprising:

at least one vibration source; and

a plurality of pixels each of which comprises:

a surface comprising first and second regions having surface finishes; and

a thin planar panel having first and second sides having surface finishes, wherein said panel is rotatably coupled to said surface so as to rotate between a first and a second position about an axis parallel to said surface, which axis defines a hinge;

wherein said panel in said first position is positioned over said first region with its second side facing said first region and wherein in said second position said panel is positioned over said second region with its first side facing said second region. Preferably, said at least one vibration source comprises a plurality of vibration sources, at least one of them associated with each pixel. Preferably, said vibration source underlies said hinge. Alternatively or additionally, said vibration source underlies a contact point between said panel and said first region. Alternatively or additionally, at least one vibration source comprises a vibration source

at a periphery of said display. Preferably, said at least one vibration source comprises a piezoelectric vibration source. Alternatively or additionally, said at least one vibration source comprises circuitry which drives said pixels to vibrate, by varying electric voltages to electrodes in the pixel.

In a preferred embodiment of the invention, the display comprises a touch-sensitive input.

There is also provided in accordance with a preferred embodiment of the invention, a visual display comprising:

a touch-sensitive input; and

a plurality of pixels each of which comprises:

a surface comprising first and second regions having surface finishes; and

a thin planar panel having first and second sides having surface finishes, wherein said panel is rotatably coupled to said surface so as to rotate between a first and a second position about an axis parallel to said surface, which axis defines a hinge;

wherein said panel in said first position is positioned over said first region with its second side facing said first region and wherein in said second position said panel is positioned over said second region with its first side facing said second region. Preferably, said touch sensitive input comprises a plurality of touch detecting elements replacing a plurality of said pixels in said display and distributed over said display. Preferably, each of said elements comprises a contact switch and a force transducing element for transferring force from a display to the switch, to close the switch. Alternatively or additionally, each of said elements comprises a piezo-resistive element and a force transducing element for transferring force from a display to the piezo-resistive, to modify its resistance.

In a preferred embodiment of the invention, said panel is flipped between said positions by the application of electric voltages to electrodes associated with the pixel and the display comprises at least one transistor associated with the pixel and deposited under said pixel for controlling said application.

There is also provided in accordance with a preferred embodiment of the invention, a visual display comprising a plurality of pixels each of which comprises:

a surface comprising first and second regions having surface finishes; and

a thin planar panel having first and second sides having surface finishes, wherein said panel is rotatably coupled to said surface so as to rotate between a first and a second position about an axis parallel to said surface, which axis defines a hinge;

wherein said panel in said first position is positioned over said first region with its second side facing said first region and wherein in said second position said panel is positioned over said second region with its first side facing said second region and

wherein said panel is flipped between said positions by the application of electric voltages to electrodes associated with the pixel and comprising at least one transistor associated with the pixel and formed under said pixel for controlling said application. Preferably, said transistor is controlled with a first, low voltage and controls a second, high voltage. Alternatively or additionally, said transistor is controlled with a signal of a short duration to allow said application of said voltages for a significantly long duration, at least twice said short duration. Preferably, said long duration is at least four times said short duration. Preferably, said long duration is at least eight times said short duration.

In a preferred embodiment of the invention, said transistor functions as a switch.

There is also provided in accordance with a preferred embodiment of the invention, a method of flipping a panel in a pixel using electrostatic forces, comprising:

counteracting stiction between said panel and a surface using field generated by applying a voltage to a levitation electrode; and

flipping said panel using a field generated by applying a voltage to a second, flipping, electrode.

There is also provided in accordance with a preferred embodiment of the invention, a method of flipping a panel in a pixel using electrostatic forces, comprising:

counteracting stiction between said panel and a surface by vibrating said panel relative to said surface; and

flipping said panel using a filed generated by applying a voltage to a flipping electrode. Preferably, the method comprises electrifying said flipping electrode to induce said vibration. Alternatively or additionally, the method comprises electrifying a second, levitating, electrode to induce said vibration. Alternatively or additionally, said vibration is effected by suitable electrifying of a piezoelectric material coupled to said panel.

There is also provided in accordance with a preferred embodiment of the invention, a display device comprising a plurality of pixels, each pixel changing state by the application of electric voltage to the pixel, wherein each pixel has associated therewith a circuit comprising at least one transistor, which at least one transistor switches said application of said voltage over a period significantly longer than a period used for addressing said circuit. Preferably, said circuit comprises fewer than ten transistors. Preferably, said circuit comprises fewer than five transistors.

There is also provided in accordance with a preferred embodiment of the invention, a micro-mechanical device, comprising:

a moving part, having a maximum dimension of less than about 0.01 millimeters;

a stationary part in contact with said moving part;

a force providing element for moving said moving part relative to said stationary part; and

a stiction countering electrode which applies an electrostatic force on said moving part, which force at least assists in breaking stiction at said contact of said stationary part and said moving part. Preferably, said force providing element comprises an electrode for applying electrostatic forces. Alternatively or additionally, said stiction countering electrode interferes with said force providing element.

BRIEF DESCRIPTION OF FIGURES

The invention will be more clearly understood by reference to the following description of preferred embodiments thereof read in conjunction with the figures attached hereto. In the figures, identical structures, elements or parts which appear in more than one figure are labeled with the same numeral in all the figures in which they appear. The figures are:

Figs. 1A-1C show schematic perspective views of a micro-machined pixel with a flipper in three different positions, in accordance with a preferred embodiment of the present invention;

Figs. 2A-2D show schematic side views of the pixel shown in Figs. 1A-1C and illustrate how electrostatic forces control movement and position of the flipper, in accordance with a preferred embodiment of the present invention;

Figs. 3A and 3B show schematic side views of a variation of the pixel shown in Figs. 1A-1C, in accordance with a preferred embodiment of the present invention, in which the structure of the pixel has been simplified in order to illustrate how electrostatic forces control movement and position of the flipper;

Fig. 4 shows schematically another pixel structure in accordance with a preferred embodiment of the present invention.

Fig. 5 shows schematically a portion of a flat-panel display comprising a two dimensional array of pixels, in accordance with a preferred embodiment of the present invention;

Figs. 6A-6D show schematically construction and operation of a multi-flipper pixel in accordance with a preferred embodiment of the present invention;

Fig. 7 shows another multi-flipper pixel, constructed in accordance with a preferred embodiment of the present invention;

Fig. 8A-8N illustrate schematically a micro-machining fabrication process for producing the pixel shown in Figs 1A-1C, in accordance with a preferred embodiment of the present invention;

Figs. 9A and 9B show schematically a perspective view and a cross-section view respectively of another pixel, constructed in accordance with a preferred embodiment of the present invention;

Figs. 10A and 10B show schematically perspective views of another pixel and a flipper respectively, constructed in accordance with a preferred embodiment of the present invention;

Fig. 11 shows schematically another pixel, in accordance with a preferred embodiment of the present invention;

Figs. 12A-12L illustrate schematically a micro-machining fabrication process for producing the pixel shown in Figs 9A-9B;

Fig. 13A is a schematic illustration corresponding to Fig. 1A and showing a levitation electrode for a flipper pixel in accordance with a preferred embodiment of the invention;

Fig. 13B is a sectional view along a line A-A in Fig. 13A;

Figs. 14A-14F, which correspond to some of Figures 8C-8M, illustrate a method of manufacturing a pixel having a levitation electrode, in accordance with a preferred embodiment of the invention;

Figs. 15A-15E illustrate a method of manufacturing a pitted nub, in accordance with a preferred embodiment of the invention;

Figs. 15F-15G illustrate an alternative method of forming a rounded nub, in accordance with a preferred embodiment of the invention;

Fig. 16 illustrates a display device including a vibration generator, in accordance with a preferred embodiment of the invention;

Figs. 17A and 17B illustrate a flipper with integral springs in respective top view and side views thereof, in accordance with a preferred embodiment of the invention;

Figs. 17C and 17D illustrate steps in manufacturing an integral flipper spring in accordance with a preferred embodiment of the invention;

Fig. 18A is a schematic circuit diagram of a touch input device, in accordance with a preferred embodiment of the invention;

Fig. 18B is a side cross-sectional view of a micro-mechanical touch input device in accordance with a preferred embodiment of the invention;

Fig. 19 is a schematic circuit diagram for a flipper-pixel, in accordance with a preferred embodiment of the invention; and

Fig. 20 is a schematic illustration of a flip-chip configuration for a device in accordance with a preferred embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figs. 1A-1C show schematic perspective views of a pixel 20 for use in a micro-mechanical display, in accordance with a preferred embodiment of the present invention. Components and elements of pixel 20 shown in Figs. 1A-1C and in the other figures are not necessarily to scale and relative dimensions in the figures have been chosen for convenience and clarity of presentation.

Pixel 20 is preferably formed on a silicon substrate 22 using micro-machining techniques. In accordance with a preferred embodiment of the present invention, pixel 20 comprises a flipper 24, first and second side electrodes 26 and 28 respectively and a central electrode 30. Preferably, a thin layer 23 of insulating material separates electrodes 26, 28 and 30 from substrate 22. Preferably, a thin planar region of substrate 22 that is contiguous with insulating layer 23 is a good conductor. In Fig. 1A flipper 24 is in an on position and in Fig. 1C flipper 24 is in an off position. In Fig. 1B, flipper 24 is shown in a position intermediate the on and off positions. Flipper 24 is preferably formed in the shape of a thin rectangular planar panel having two relatively large surfaces, a first face surface 40 shown in Fig. 1A and a second face surface 42 shown in Figs 1B and 1C. Flipper 24 is preferably formed with mounting holes 32 and 34. U brackets 36 and 38 loop through mounting holes 32 and 34 respectively and loosely bracket flipper 24 to central electrode 30 so that flipper 24 is rotatable back and forth between the on and off positions of flipper 24.

For a black and white and/or gray level flat-panel display, in accordance with a preferred embodiment of the present invention, first face surface 40 (Fig. 1A) is preferably treated so that it is white. Second face surface 42 (Figs. 1B and 1C) is preferably treated so that it is black. First electrode 26 is preferably treated so that its surface is black and second electrode 28 is preferably treated so that its surface is white. Preferably, a portion 29 (Fig. 1A) of the surface of central electrode 30 that is visible when flipper 24 is in the on position is treated so that it is white. Preferably, a portion 31 of central electrode 30 that is visible when flipper 24 is in the off position (Fig. 1C) is treated so that it is black. Black colored surfaces are shown shaded and white colored surfaces are shown without shading.

When flipper 24 is in the on position shown in Fig 1A, flipper 24 covers substantially completely first electrode 26 and portion 31 (Fig. 1C) of electrode 30 that are black.

Substantially all surfaces in pixel 20 that are visible are white and pixel 20 appears white. With flipper 24 in the off position shown in Fig. 1C, flipper 24 substantially completely covers electrode 28 and portion 29 (Fig. 1A) of central electrode 30 that are white. As a result, substantially all surfaces in pixel 20 that are visible are black and the pixel therefore appears black.

It should be noted that regions and elements of pixel 20 that are described as being treated to be black or white can be treated to display colors other than black or white. In particular, for example, regions and elements of pixel 20 that are white can be treated to have a color that is one of the primary RGB colors. Pixel 20 in the on position will therefore display one of the RGB colors accordingly and in the off position the pixel 20 will be black. Pixels 20 treated to have different ones of the RGB colors are useable, in accordance with a preferred embodiment of the present invention, to provide a color flat-panel display.

Motion of flipper 24 between on and off positions is controlled, in accordance with a preferred embodiment of the present invention, by electrostatic forces between flipper 24 and first and second electrodes 26 and 28.

In order to generate and control these electrostatic forces, preferably flipper 24 and U brackets 36 and 38 are made from a conducting material such as polysilicon or aluminum. Preferably flipper 24 is in conductive electrical contact with central electrode 30 and/or U brackets 36 and 38. As a result, voltage on flipper 24 is always substantially equal to voltage applied to central electrode 30. Preferably, conductive electrical contact between flipper 24 and electrode 30 is achieved as a result of physical contact between regions of flipper 24 and regions of electrode 30 and U brackets 36 and 38.

In addition, flipper 24 is preferably substantially isolated from conductive electrical contact with first and second electrodes 26 and 28. Preferably, conductive electrical contact between flipper 24 and first electrode 26 is prevented when flipper 24 is in the on position respectively by providing first electrode 26 with insulation nubs 44. Insulation nubs 44 on first electrode 26 are shown in Figs. 1B and 1C. Preferably, conductive electrical contact between flipper 24 and second electrode 28 is prevented when flipper 24 is in the off position by providing flipper 24 with insulation nubs 45 on face surface 40 shown in Fig. 1A. Preferably, insulation nubs 44 and 45 are formed from a material that is a poor conductor. In some preferred embodiments of the present invention, an insulating coating is used to cover insulation nubs 44 to make them non-conductive. Insulation nubs 44 and 45 not only prevent electrical contact between flipper 24 and electrodes 26 and 28 respectively, they also reduce stiction forces between flipper 24 and electrodes 26 and 28.

Insulation nubs 44 and 45 prevent direct physical contact between flipper 24 and first and second electrodes 26 and 28. When flipper 24 is in the on position (Fig. 1A), flipper 24 rests on insulation nubs 44 of electrode 26 and does not make direct contact with first electrode 26. Because insulation nubs 44 are poor conductors, flipper 24 is substantially electrically isolated from first electrode 26. Little or no current flows between flipper 24 and electrode 26 even if a potential difference exists between electrode 26 and electrode 28. Similarly, when flipper 24 is in the off position (Fig. 1C), flipper 24 rests on insulation nubs 45 on face surface 40 of flipper 24 and flipper 24 is substantially electrically isolated from second electrode 28.

Figs. 2A-2D illustrate schematically how electrostatic forces generated by applying voltages to electrodes 26, 28 and 30 control movement of flipper 24, in accordance with a preferred embodiment of the present invention. In Figs. 2A-2D views of pixel 20 are shown in profile facing the short edge of flipper 24. In the preferred embodiment shown in Figs. 2A-2D the conducting layer of substrate 22 that is contiguous with insulating layer 23 is grounded. This is indicated in Figs. 2A-2D and in other figures that follow, by showing substrate 22 as grounded. The conducting layer acts as a ground plane for pixel 20.

Fig. 2A shows pixel 20 with flipper 24 in the on position corresponding to the position of flipper 24 shown in Fig. 1A, in which pixel 20 is white. In the on position flipper 24 rests on central electrode 30 and insulation nubs 44, only one of which is shown, of first electrode 26. In Fig. 2A central electrode 30 is shown charged to a positive voltage "$+V_L$" and electrodes 26 and 28 are grounded. (The choice of sign for the voltage is arbitrary and a positive voltage is assumed for convenience.) Because flipper 24 is in contact with central electrode 30, flipper 24 is also at $+V_L$. As a result, flipper 24 has a net positive charge distribution indicated schematically in Fig. 2A by plus signs. The positive charges on flipper 24 induce negative charges, shown schematically by minus signs, on first electrode 26. Electrostatic attraction between the positive and negative charges prevents flipper 24 from moving away from first electrode 26 and flipper 24 is locked in the on position. Since insulation nubs 44 are substantially non-conducting, substantially no current flows between central electrode 30 and first electrode 26 through flipper 24. As a result, with flipper 24 locked in the on position substantially no energy is dissipated in pixel 20.

It should be noted that whereas in Fig. 2A first electrode 26 is shown grounded, first electrode 26 does not necessarily have to be grounded for an attractive electrostatic force to exist between flipper 24 and first electrode 26. As long as there is a potential difference between flipper 24 and electrode 26 there is an attractive force between them. In accordance

with a preferred embodiment of the present invention, voltages other than those shown in Fig. 2A, can be used to lock flipper 24 in the on position if they provide required voltage differences between the electrodes and the flipper.

Flipper 24 is locked in the off position, corresponding to Fig. 1C in which pixel 20 is black, in similar manner to the way that flipper 24 is locked in the on position. Preferably second electrode 28 is grounded and central electrode 30 to voltage $+V_L$. A voltage $+V_L$ applied to central electrode 30 to lock flipper 24 in an on or off position is hereinafter referred to as a "locking voltage".

In accordance with a preferred embodiment of the present invention, flipper 24 is "unlocked" from the on position and flipped to the off position by applying a same voltage to central electrode 30 and first electrode 26 and grounding electrode 28. Charges on electrodes 26 and 30 and on flipper 24 (as a result of being in contact with electrode 30) resulting from the applied voltages induce charges on electrode 28 that are opposite in sign to the charges on electrodes 26, 30 and flipper 24. The charges on electrodes 26, 28 and 30 and flipper 24 generate electrostatic forces that operate to lift flipper 24 away from first electrode 26 and flip it to second electrode 28. The voltage applied to central electrode 30 and first electrode 26 is chosen large enough so that the electrostatic forces are strong enough to overcome stiction and the force of gravity acting on the mass of flipper 24. In some embodiments of the invention, a constant voltage is applied. In other embodiments, the voltage may be varied over the course of movement of the flipper. For example, a higher voltage may be provided at the beginning of the movement to overcome stiction.

Fig. 2B schematically shows charge distributions on central electrode 30 and first electrode 26 in which both central electrode 30 and first electrode 26 are raised to a same positive potential $+V_F$ (chosen positive for convenience) in order to flip flipper 24 from the on position to the off position. The positive charges on central electrode 30, first electrode 26 and flipper 24 induce negative charge on second electrode 28. An electrostatic field that results from the positive and negative charges generates a force that acts on flipper 24 in a direction indicated by arrow 25. Force 25 lifts flipper 24 away from first electrode 24 and rotates flipper 24 away from first electrode 24 towards second electrode 28, so that flipper 24 flips to the off position.

Flipper 24 may be similarly flipped from the off position back to the on position, in accordance with a preferred embodiment of the present invention, by applying voltage $+V_F$ to central electrode 30 and second electrode 28. This is schematically illustrated in Fig. 2C in

which positive charge distributions are produced on flipper 24 and second electrode 28 by the application of $+V_F$ to central electrode 30 and second electrode 28. The positive charge distributions induce a negative charge distribution on first electrode 26. An electrostatic field that results from the charge distributions generates a force on flipper 24 in a direction indicated by arrow 27.

Fig. 2D shows schematically an alternate way of flipping flipper 24 between on and off positions, in accordance with a preferred embodiment of the present invention. In Fig 2D flipper 24 is shown in the off position with central electrode 30 and second electrode 28 grounded. First electrode 26 is charged to a positive potential V_F. A resultant positive charge distribution on first electrode 26 induces a negative charge distribution on flipper 24 and on second electrode 28. The positive and negative charge distributions generate a net force on flipper 24 that operates in a direction indicated by arrow 29 to lift flipper 24 away from second electrode 28 and rotate flipper 24 towards first electrode 26.

The present inventors have simulated electrostatic fields generated by voltages applied to electrodes 26, 28 and 30 of pixel 20 in the configurations shown in Figs. 2C and 2D on a computer using the ANSYS finite elements analysis program (available from Ansys, Inc., Houston TX USA). Forces 27 and 29 shown respectively in Figs 2C and 2D were determined from the simulated electrostatic fields. The inventors found that force 27 is equal to force 29 if the magnitude of V_F is the same in both cases. For the same voltage V_F, the method of flipping flipper 24 shown in Fig. 2C and the method for flipping flipper 24 shown in Fig. 2D generate a same "flipping force". A voltage V_F used to flip flipper 24 between on and off positions is hereinafter referred to as a "flipping voltage".

The equivalence of the Fig. 2C and 2D methods of flipping flipper 24 may be understood from consideration of a pixel 50 shown in Figs. 3A and 3B, which is an "idealized" version of pixel 20. Figs. 3A and 3B show pixel 50 in a side view equivalent to the side view of pixel 20 shown in Figs. 2A–2D. In both Figs. 3A and 3B flipper 24 is in the off position.

Pixel 50 comprises substantially the same components as pixel 20. In pixel 50 however, insulation nubs 44 and 45 are omitted. Central electrode 30 has been "shrunk" to an electrical contact point 30 used for connecting flipper 24 to a power source. U brackets 36 and 38 are replaced by hinges 52, only one of which is shown in the perspective of Figs 3A and 3B, that enable flipper 24 to flip back and forth between on and off positions.

First and second electrodes 26 and 28 and flipper 24 are substantially the same size. Flipper 24 is assumed to be coated with an insulating coating (not shown) that substantially

isolates flipper 24 from first and second electrodes when flipper 24 is in the on and off positions respectively. Substrate 22 is grounded so that the conducting layer of substrate 22 that is contiguous with insulating layer 23 functions as a ground plane of pixel 50.

In Fig. 3A, flipper 24 and second electrode 28 are both raised to a positive voltage $+V_F$ (positive for convenience of presentation only) and first electrode 26 is grounded. The voltage configuration shown in Fig. 3A is the same as the voltage configuration of electrodes, 26, 28 and 30 and flipper 24 of pixel 20 shown in Fig. 2C. In Fig. 3B, flipper 24 and second electrode 28 are grounded and first electrode 26 is raised to V_F. The voltage configuration shown in Fig. 3B is the same as the voltage configuration of electrodes, 26, 28 and 30 and flipper 24 of pixel 20 shown in Fig. 2D. Plus and minus charge distributions on electrodes 26, 28, 30, flipper 24 and on the boundary between insulating layer 23 and substrate 22 of pixel 50 are shown schematically by plus and minus signs.

Referring to Fig. 3A, as a result of raising second electrode 28 and flipper 24 to voltage V_F positive charge is deposited on second electrode 28 and on flipper 24. Since second electrode 28 and flipper 24 are conductors and electrically connected together by their being connected to a same voltage, first electrode 28 and flipper 24 may be considered to function as a single conductor. As a result, none of the deposited positive charge resides (in the idealized geometry of pixel 50) at the boundary between second electrode 28 and flipper 24. The charge resides, as shown in Fig. 3A, on the outside surfaces of the volume of the "single conductor" formed by second electrode 28 and flipper 24. The positive charge in second electrode 28 is concentrated at a boundary region 54 between second electrode 28 and insulating layer 23. The positive charge in flipper 24 is concentrated on face surface 42 (only an edge of which is shown in the perspective of Fig. 3A) of flipper 24.

The positive charge in second electrode 28 induces a negative charge in the conducting layer of substrate 22. The negative charge in substrate 22 is concentrated at a boundary region 56 between substrate 22 and insulating layer 23. Except for edge effects, the electrostatic field generated by the charges at the boundary regions 54 and 56 of insulating layer 23 is confined to a volume of insulating layer 23 between the charges and has little effect outside this volume. Second electrode 28, the conducting layer of substrate 22 and the region of insulating layer 23 between them function as a thin parallel plate condenser. The amount of positive charge on second electrode 28 can be estimated from the capacitance of the parallel plate condenser, which is determined by dimensions of second electrode 28 and insulating layer 23 and the dielectric constant of the material of insulating layer 23.

The positive charges on face surface 42 of flipper 24, and substantially only these charges (except for edge effects), induce negative charges on first electrode 26 since the charges at boundary regions 54 and 56 do not generate a field outside of insulating layer 23. As a result the amount and distribution of the positive and negative charges on flipper 24 and first electrode 26 depend substantially only on the shapes of first electrode 26 and flipper 24, and the potential difference V_F between them. Therefore an electrostatic field in the space above flipper 24 and first electrode 26 is a function substantially only of the shapes and relative positions of first electrode 26 and flipper 24 and on V_F. It follows then that force 27 generated by the electrostatic field that operates to lift flipper 24 away from second electrode 28 and towards first electrode 26 is substantially only a function of the shapes and relative positions of first electrode 26 and flipper 24 and V_F.

A similar analysis of the charge distributions shown in Fig. 3B leads to a same conclusion as that reached for the charge distributions shown in Fig. 3A. An electrostatic field in the space above flipper 24 and first electrode 26 in Fig. 3B is a function substantially only of the shapes and relative positions of first electrode 26 and flipper 24 and on the voltage difference V_F between them. Similarly, force 29 in Fig. 3B that operates to lift flipper 24 away from second electrode 28 and towards first electrode 26 is substantially only a function of the shapes and relative positions of first electrode 26 and flipper 24 and V_F.

The shapes and relative positions of first electrode 26 and flipper 24 are the same in Fig. 3A and 3B. Except for being of opposite polarity, the potential difference between flipper 24 and first electrode 26 are the same. As a result, the electrostatic fields generated in the space above flipper 24 and first electrode 26 in Figs. 3A and 3B are identical except for polarity. Therefore forces 27 and 29 in Figs. 3A and 3B that act to lift flipper 24 away from second electrode 28 are identical. Applying the results of the analysis for the "ideal" pixel 50 to pixel 20 shown in Figs. 2C and 2D leads to the conclusion that forces 27 and 29 and therefore the methods for flipping flipper 24 shown in Figs. 2C and 2D respectively are substantially the same.

The deposited and induced charges on flipper 24, first electrode 26 and second electrode 28 in the various voltage configurations that are used to rotate flipper 24 between on and off states are generally concentrated close to the axis of rotation of flipper 24. Therefore, forces that act on flipper 24 are also concentrated near to the axis of rotation of flipper 24. As a result, most of the torque that rotates flipper 24 is generated by forces that act on relatively short lever arms. In addition, the strength of the forces are substantially proportional to inverse

squares of distances between points on flipper 24 and points on electrode 26 or 28 to which flipper 24 is to be rotated.

A geometry in which first and second electrodes 26 and 28 are substantially coplanar, as shown in pixels 20 and 50, maximizes the concentration of charge near to the axis of rotation of flipper 24. In addition for a given distance between edges of first and second electrodes 26 and 28 that are close to the axis of rotation of flipper 24, a coplanar geometry for electrodes 26 and 28 maximizes distances between points on the two electrodes. As a result, for a given flipping voltage and given distance between "close edges" of electrodes 26 and 28, flipping forces are minimized when electrodes 26 and 28 are coplanar.

Therefore, in some preferred embodiments of the present invention, in order to increase flipping forces for a given flipping voltage, first and second electrodes 26 and 28 are angled so that the angle between their planes is less than 180°. Fig. 4 shows a pixel 60, in accordance with a preferred embodiment of the present invention, in which an angle θ between the planes of first and second electrodes 26 and 28 is less than 180°. Preferably, θ is between 140° and 180°. More preferably θ is between 150° and 180°.

The area of pixel 20, or other pixel in accordance with a preferred embodiment of the present invention, is preferably a square millimeter or less. Preferably flipper 24 is less than 1000 microns long and 500 microns wide. These dimensions provide a square pixel 1-mm on a side. For some applications flipper 24 is preferably less than 100 microns long and 50 microns wide, which provides a square pixel approximately 100 microns on a side. A pixel of this size is suitable for providing a black and white (two level) display having a resolution of 250 DPI.

In a preferred embodiment of the present invention flipper 24 is formed from polysilicon and has dimensions 1 x 14 x 83 microns, resulting in a pixel having dimensions approximately 28 x 83 microns. Electrodes 26, 28 and 30 are also preferably formed from polysilicon and are preferably 0.5 microns thick. Insulation nubs 44 and 45 are preferably about 1.5 microns high. For these dimensions and materials, the inventors have determined that flipper 24 can be flipped between on and off positions in a time on the order of 12 milliseconds using a flipping voltage substantially equal to five volts. A locking voltage of about 2.5 volts locks flipper 24 into an on or off position.

Pixels 20 that are 28 x 83 microns can be used, in accordance with a preferred embodiment of the present invention, to provide a black and white or gray level flat-panel display. A flat-panel display comprising pixels 20 of this size has a resolution of 300 DPI in a first dimension and approximately 900 DPI in a second dimension.

Alternatively, pixels 20 of this size can be used to provide a flat-panel color display, in accordance with a preferred embodiment of the present invention. For a flat-panel color display the areas of pixel 20 that are treated to be white in Figs 1A-1C are treated to have one of the RGB colors. Each pixel of the flat-panel color display is a "super pixel", substantially square and approximately 83 microns on a side, comprising three pixels 20, each of which has a different RGB color.

It should be realized that although pixels 20 have been described as being white, black or one of the RGB primary colors, surfaces of pixels 20 can be treated to have other colors or finishes, in accordance with preferred embodiments of the present invention.

Fig. 5 shows schematically part of a black and white flat-panel display 62 comprising a plurality of rectangular pixels 20, in accordance with a preferred embodiment of the present invention. In flat-panel display 62 the positions of flippers 24 in pixels 20 are controlled by row and column control lines 64 and 66 respectively. Each row control line 64 is connected to first electrode 26 of each pixel 20 in a row of pixels in flat-panel display 62. Each column control line 54 is connected to central electrode 30 in each pixel 20 in a column of pixels in flat-panel display 62. Second electrodes 28 in all pixels 20 are permanently grounded. (In a color flat-panel display comprising super pixels, each super pixel 64 would comprise three pixels 20 in a column of pixels shown in Fig. 5, so as to form a substantially square super pixel. Each one of the pixels 20 in a super pixel would display instead of white in the on position a different one of the RGB colors.)

In flat-panel display 62, a flipper 24 of a pixel 20 is flipped from on to off using the method described in the discussion of Fig. 2B in which both central electrode 30 and first electrode 26 are charged to a flipping voltage. Flipper 24 is flipped from off to on using the method described in the discussion of Fig. 2D, in which central electrode 30 is grounded and a flipping voltage is applied to first electrode 26. Flipper 24 is locked in an on position or an off position using the method shown in Fig. 2A in which central electrode 30 is charged to a locking voltage and first and second electrodes 26 and 28 are grounded. Hereinafter, setting flipper 24 of a pixel 20 to an on or off position is also referred to as setting or turning pixel 20 to on or off respectively.

To form an image on flat-panel display 62, pixels 20 are set to on or off, as required to form the image, row by row. Setting pixels 20 in a row to on or off begins with all row control lines 64 of flat panel display 62 grounded and all column control lines 66 of flat panel display 62 raised to a locking voltage. Column control lines 66 of pixels 20 in the row that are to be set to on are then grounded and column control lines 66 of pixels 20 in the row that are to be set to

off are left at the flipping voltage. Row control line 64 of the row is then set to the flipping voltage. When this happens, all pixels 20 in the row are simultaneously set to their desired on or off states in a time, hereinafter referred to as a "flip time", that it takes a flipper 24 to flip between an on and off position. Flippers 24 of pixels 20 in the row that have their column control lines 66 set to zero remain in the on position if they are in the on position or flip to on if they are in the off position. Flippers 24 of pixels 20 in the row that have their column control lines 66 set to the flipping voltage stay in the off position if the are already in the off position or flip to the off position if they are in the on position. After pixels 20 in the row are set row control line 64 of the row is grounded.

Before continuing on to set pixels 20 in a next row in the same manner, all column control lines 66 in flat-panel display 62 are set to the locking voltage for a short period of time. This assures that all pixels 20 in other rows whose flippers 24 may have begun to dislodge from their respective on and off positions during the time that the row of pixels was being set, as a result for example of a vibration in flat-panel display 62, are safely returned to their positions. In this way pixels 20 in flat-panel display 62 are never left unlocked long enough for a pixel 20 to change its state unintentionally. (During the time that each row is being set some of the row control lines 66 are grounded leaving many pixels 20 unlocked.)

After all the pixels 20 in display 62 are properly set, all column control lines 66 are raised to the locking voltage to lock the pixels in the on and off states to which they have been set. The time it takes to form an image on flat panel display 62 is substantially equal to the number of rows in flat-panel display 62 times the flip time of the pixels in the flat-panel display.

In some flat-panel displays, in accordance with preferred embodiments of the present invention, an image is formed in a time that is much shorter than the time it takes to form an image in flat-panel display 62. The image is formed in a time substantially equal to the flip time of pixels 20 in the display rather than in a time substantially equal to a product of the flip time and the number of rows in the display.

This is achieved in a flat-panel display, in accordance with a preferred embodiment of the present invention, by providing each pixel 20 with addressable switches. The addressable switches are controllable to connect central electrode 30 and first electrode 26 of the pixel to ground or to a voltage output of a display power source independently of each other. In this way each pixel 20 is individually controllable and the setting of a pixel 20 to on or off in the display is uncoupled from the setting of other pixels in the display. The voltage output of the power supply is such that it can be set to ground or to appropriate locking and flipping

voltages. When the voltage output is set to the locking or flipping voltage, the power source can substantially simultaneously charge electrodes 26 and 30 of all pixels 20 in the display to the locking or flipping voltage in a time substantially less than the flip time of the pixels.

To form an image on the flat-panel display, in accordance with a preferred embodiment of the present invention, the voltage output of the power supply is grounded. All the addressable switches in the display are addressed using an appropriate scanning procedure and controlled to connect first electrode 26 and central electrode 30 of pixels 20 to ground or to the power source. For pixels 20 that are to be set to on, central electrode 30 is connected to ground and first electrode 26 is connected to the output of the power source. For pixels 20 that are to be set to off, both central electrode 30 and first electrode 26 are connected to the voltage output. The voltage output is then raised to the flipping voltage, which causes all pixels 20 in the display to flip to their desired on or off state substantially simultaneously. First electrodes 26 of all pixels 20 are then connected to ground, all central electrodes of pixels 20 are connected to the voltage output and the voltage output is set to the locking voltage. This locks all pixels 20 in the on or off states to which they were set.

Scanning and setting the switches occur in a time that is very short compared to the flip time of pixels 20. As a result, the total time required to set and lock pixels 20 in their appropriate on or off states so as to form the image is substantially equal to the flip time of pixels 20.

Various configurations of power sources and switches in pixels 20 can be used to form a flat-panel display, in accordance with preferred embodiments of the present invention, in which pixels 20 are individually and/or simultaneously controllable to be switched on and off. These configurations will readily occur to persons of the art.

Preferably, an array of pixels 20 that are individually and/or simultaneously controllable, in accordance with a preferred embodiment of the present invention, is formed as a mono-block in a process that integrates layers of electronic and mechanical components to form a single unit.

In some preferred embodiments of the present invention a pixel comprises more than one flipper. Whereas a pixel that has a single flipper has two states, an on and off state, a pixel, in accordance with a preferred embodiment of the present invention, comprising a plurality of "N" flippers has (N+1) states. A multi-flipper pixel can therefore display a greater variety of colors than a pixel having a single flipper.

Figs. 6A-6D show schematically a perspective view of a multi-flipper pixel 160, in accordance with a preferred embodiment of the present invention. Pixel 160 comprises two

flippers, a first flipper 162 and a second flipper 164. Multi-flipper pixel 160 has three states, first, second and third states, that are shown in Figs. 6A-6C respectively. Fig. 6D shows an exploded plan view of pixel 160 in the second state, which is shown in Fig. 6B.

Multi-flipper pixel 68 comprises a substrate 22 having an insulating layer 23. First and second lateral electrodes 26 and 28 and first, second, third and fourth central electrodes 171, 172, 173 and 174 are formed on insulating layer 23. First, second, third and fourth central electrodes 171, 172, 173 and 174 are most clearly shown in Fig. 6A and Fig. 6D.

First flipper 162 is coupled to pixel 160 by a pair of brackets 176, each of which loops through a different mounting hole 178 in first flipper 162. One of brackets 176 is anchored to second central electrode 172 and the other to third central electrode 173. Brackets 176 are preferably formed from a conducting material. First flipper 162 is in electrical contact with second and third central electrodes 172 and 173 and brackets 176. Preferably, electrical contact is achieved by physical contact of regions of first flipper 162 with regions of second and third central electrodes 172 and 173 and brackets 176.

Second flipper 164 is coupled to pixel 160 by a pair of brackets 180 that loop through mounting holes 182 in second flipper 164. One of brackets 180 is anchored to first electrode 171 and the other to fourth electrode 174. Brackets 180 are preferably formed from a conducting material. Second flipper 164 is in electrical contact with first and fourth central electrodes 171 and 174 and brackets 180. Preferably, electrical contact is achieved by physical contact of regions of second flipper 164 with regions of first and fourth central electrodes 171 and 174 and brackets 180.

The mounting of brackets 176 and 180 to their respective central electrodes are most clearly shown in Fig. 6A. Mounting holes 178 and 182 and the manner in which brackets 176 and 180 loop through their respective mounting holes 178 and 182 respectively is most clearly shown in Fig. 6B.

Referring to Fig. 6B, first flipper 162 is preferably formed with clearance slots 184 that are large enough so that no part of flipper 162 makes electrical contact with first and fourth central electrodes 171 and 174 or any part of brackets 180. Similarly, second flipper 164 is preferably formed with clearance slots 186 that are large enough so that no part of second flipper 164 makes electrical contact with second and third central electrodes 172 and 173 or any part of brackets 176. External surfaces of brackets 176 and 180 are preferably covered with a layer of insulating material to assist in prevention of undesirable electrical contact with first and second flippers 162 and 164 respectively. First and second flippers 162 and 164 are preferably electrically isolated from each other and from first and second lateral electrodes 26

and 28 by appropriately placed non-conductive insulation nubs (not shown) or by layers of insulating material deposited on their surfaces. Mounting holes 178 and clearance slots 184 of flipper 162 and mounting holes 182 and clearance slots 186 of flipper 164 are most clearly shown in exploded plan view 6D.

A control line 190 is connected to second and third central electrodes 172 and 173 for applying voltage to second and third central electrodes 172 and 173 and thereby to first flipper 162. Connections between control line 190 and second and third central electrodes 172 and 173 are shown in Fig. 6A and Fig. 6D. A control line 192 is connected to first and fourth central electrodes 171 and 174 for applying voltage to first and fourth central electrodes 171 and 174 and thereby to second flipper 164. Connections between control line 192 and first and fourth electrodes 171 and 174 are shown in Fig. 6C and Fig. 6D. First lateral electrode 26 is connected to a control line 194 and second lateral electrode 28 is preferably permanently grounded.

First and second lateral electrodes 26 and 28 and each of the face surfaces of flippers 162 and 164 of pixel 160 are preferably treated to display one of the RGB colors. By appropriate choice of which electrodes 26 and 28 and face surfaces are treated to display which one of the RGB colors, pixel 160 displays a different one of the RGB colors in each one of its three different states. Exposed surfaces of first and second lateral electrodes 26 and 28 and face surfaces of first and second flippers 162 and 164 are labeled in each of Figs. 6A-6C with the RGB color that they display. In Fig 6A, which shows pixels 160 in a first state, pixel 160 displays a substantially saturated red color. In second and third states of pixel 160, which are shown respectively in Figs. 6B and 6C, pixel 160 displays a substantially saturated blue and green color respectively. The choice of colors for face surfaces of flippers 162 and 164 and electrodes 26 and 28 are chosen by way of example and other color choices are possible and can be advantageous. For example the face surfaces of flippers 162 and 164 can be treated so that they display different levels of gray. Instead of displaying one of the RGB colors in each of its states, pixel 160 will then display a different gray level in each of its states.

Switching between first second and third states is accomplished in a manner similar to the way in which pixel 20 is switched between on and off states. For example, to switch pixel 160 from its first state shown in Fig. 6A to its second state shown in Fig. 6B flippers 162 and 164 are grounded and first lateral electrode 26 is raised to a flipping voltage. To switch pixel 160 from its second state to its third state shown in Fig. 6C, first lateral electrode 26, second flipper 164 and second lateral electrode 28 are grounded while first flipper 162 is raised to the flipping voltage. To switch pixel 160 back from its third state to its second state (Fig. 6B) first

and second lateral electrodes 26 and 28 are grounded and first and second flippers 162 and 164 are raised to the flipping voltage. Pixel 160 is switched from second state to first state (Fig. 6B to Fig. 6A) by raising second flipper 164 to the flipping potential while grounding first lateral electrode 26 and first flipper 162.

To lock pixel 160 in any one of its states, first and second lateral electrodes 26 and 28 are grounded and voltages are applied to first and second flippers 162 and 164 so that appropriate small voltage differences are generated between adjacent lateral electrodes and flippers.

Fig. 7 shows schematically a perspective view of another multi-flipper pixel 200, in accordance with a preferred embodiment of the present invention. Pixel 200 comprises two flippers 202 and 204. Multi-flipper pixel 200 is shown in a second state similar to the second state of multi-layer pixel 160 shown in Fig. 6B. Flipper 202 is coupled to a first central electrode 206 by two box hinges 208 that capture mounting extensions 210 (only one of which is shown) that protrude from flipper 202. Similarly, flipper 204 is coupled to a second central electrode 212 by two box hinges 214 that capture mounting extensions 216 (only one of which is shown). Flipper 202 is formed with clearance slots 218 that enable flipper 202 to clear both sets of box hinges 208 and 214 when flipper 202 is flipped from the position in which it is shown in Fig. 7 to a position in which it lies on top of flipper 204. Flipper 204 has similar clearance slots 220.

Figs. 8A-8I illustrate schematically a fabrication procedure, in accordance with a preferred embodiment of the present invention, for forming pixel 20 shown in Figs 1A – 1C.

Fig. 8A shows a first step in the fabrication process in which a substrate 22, preferably formed from a silicon wafer, is covered with a thin insulating layer 23, formed from a material such as silicon nitride.

Fig. 8B shows a next step in the fabrication procedure in which insulating layer 23 is covered with a layer 80 of conducting material, such as polysilicon or a metal such as aluminum. Conducting layer 80 is then etched to form first and second electrodes 26 and 28 and central electrode 30, which electrodes 26, 28 and 30 are shown after they are formed in Fig. 8C.

First, second and central electrodes 26, 28 and 30, and exposed surfaces of substrate 22 are then covered with a sacrificial layer 82 shown in Fig. 8D from an appropriate material such as silicon dioxide. Insulation nub wells 81 and insulation nub holes 83 are then etched into sacrificial layer 82. Insulation nub wells 81 are blind holes in sacrificial layer 82 that do not penetrate all the way to second electrode 28. Insulation nub holes 83 are through holes that

penetrate all the way to first electrode 26. Insulation nub wells 81 are used to form insulation nubs 45 (Fig. 1A) on flipper 24 whereas insulation nub holes 83 are used to form insulation nubs 44 on first electrode 26. A layer 84, shown in Fig. 8E, of conducting material such as polysilicon or aluminum is then deposited on sacrificial layer 82. Conducting layer 84 is then etched, preferably to the depth of sacrificial layer 82 to form flipper 24 with mounting holes 32 and 34, as shown in Fig. 8F. In Fig. 8F insulation nub holes 83 are filled with the material of layer 84 that form insulation nubs 44 on first electrode 26.

A second sacrificial layer 86, shown in Fig. 8G, is then deposited on the formed flipper 24 and exposed surface of sacrificial layer 82. Preferably, sacrificial layer 86 is formed from silicon dioxide if polysilicon is used as a material for flipper 24 and a polymer if aluminum is used as a material for flipper 24.

The shape of sacrificial layer 86 follows contours of surfaces on which it is deposited. As a result, sacrificial layer 86 has a step 85 in the vicinity of an edge 87 of flipper 24 and depressions 89 over mounting holes 32 and 34. Fig. 8H shows schematically a cross-section of the layers of pixel 20 that are shown in Fig. 8G, which cross-section is taken along a line A – A in Fig. 8G. The plane of the cross-section passes through the center of a depression 89. In the cross-section flipper 24 appears to have two disconnected parts, a large part 91 and a small part 93. Small part 93, hereinafter referred to as "axle part 93", is a part of flipper 24 that loops through U-bracket 38 of pixel 20 (Figs. 1A – 1C). Large part 91, hereinafter referred to as body part 91 is part of the body of flipper 24. Axle part 91 is not separate from body part 93 but appears so because the plane of the cross-section passes through mounting hole 34 (Fig. 8F) of flipper 20.

Following deposition of sacrificial layer 86, four holes 90 are "drilled" through sacrificial layers 86 and 82 all the way to the surface of central electrode 30 using methods known in the art, such as by plasma or other etching. The tops of two of holes 90 are shown in Fig. 8I. One other holes 90 is drilled through sacrificial layers 86 and 82 at the locations of each of depressions 89 and are not shown in the perspective of Fig. 8I. Fig. 8J shows schematically two holes 90 and layers of pixel 20 in a cross-section view along line A - A in Fig. 8I.

Holes 90 and depressions 89 are used as molds for forming parts of the "legs" of U brackets 36 and 38 (Figs. 1A-1C) that loop through mounting holes 32 and 34 of flipper 24. The locations of holes 90 determine where on central electrode 30 the legs of U-brackets 36 and 38 are anchored. Holes 90 are not flush with regions of layer 86 that cover axle part 93 but are displaced from these regions. Technical limitations in the accuracy of placement of holes

90 require that holes 90 be distanced from regions of layer 86 that cover axle part 93 to prevent these regions being damaged in the process of forming holes 90. Sacrificial layer 86 serves to physically isolate axle part 93 (and body part 91) from a next conducting layer 92, shown in Figs. 8K and 8L, that is deposited on layer 86 and other exposed areas of pixel 20. Layer 92 is used to form U-brackets 36 and 38. Damage to regions of layer 86 contiguous with axle portion 93 could result, for example, in axle part 93 being frozen to U-bracket 38, which would thereby render flipper 24 not rotatable.

The conducting material of layer 92 that is deposited on pixel 20 following the deposition and drilling of layer 86 fills holes 90 and lines the walls of depressions 89. Fig. 8L shows layer 92 in a cross-section taken along line A – A of Fig. 8K. Preferably, layer 92 is formed from polysilicon. Layer 92 is etched away to form upper parts of brackets 36 and 38. (The lower parts of U-brackets 36 and 38 are formed by holes 90 and depressions 89 into which the material of layer 90 is deposited). Sacrificial layers 86 and 82 are then eroded away using methods known in the art to leave a fully formed pixel 20 shown in Fig. 8M. A cross-section of pixel 20 along line A – A in Fig. 8M is shown in Fig. 8N.

Brackets 36 and 38 in Figs. 8M and 8N show some details resulting from the manufacturing process illustrated in Figs. 8A – 8L that were not shown in brackets 36 and 38 in previous figures. Among these details are external shoulders 97 shown in Figs 8M and 8N and internal shoulders 99 shown in Fig. 8N. Shoulders 97 and 99 result from the positioning of holes 90 which was discussed in the description of Figs. 8I and 8J. The uneven widths of the legs of U-brackets 36 and 38, which are shown in Fig 8M result from differences in the size of holes 90 and the parts of U-brackets 36 and 38 that are formed by etching away material of layer 92. In previous figures the shapes of U-brackets 36 and 38 were simplified and these details were not shown in the interests of clarity of presentation.

It should be noted that if axle part 93 falls below shoulders 99 shown in Fig 8N undesirable "play" in the position of flipper 24 is increased. In addition, if axle part 99 falls below a shoulder 99 flipper 24 can get jammed under the shoulder and be prevented from rotating freely. The height of shoulders 99 is determined by the thickness of sacrificial layer 82. In order to prevent flipper 24 from falling below a shoulder 99 the thickness of sacrificial layer 82 in the production process shown in Figs. 8A - 8N must be less than the thickness of layer 91 from which flipper 24 is formed.

In pixels for which the thickness of layer 91 is thicker than the thickness of flipper 24, brackets 36 and 38 are produced using a method in which the height of shoulders 99 is not determined by the thickness of sacrificial layer 82 or brackets different from brackets 36 and 38

are used to couple flipper 24 to central electrode 30. It can be advantageous to use a relatively thick sacrificial layer 82 in order to increase the space between flipper 24 and first electrode 26 and second electrode 28 when flipper 24 is in the on and off position respectively in order to decrease stiction. A possible manufacturing procedure for producing brackets 36 and 38 with "low' shoulders is discussed at the end of the discussion of Fig. 12L.

Other pixels and brackets for mounting flippers to pixels, in accordance with preferred embodiments of the present invention are shown in Figs. 9A-11. Pixels and brackets shown in Figs. 9A - 11 are produced using fabrication procedures that are variations of the procedure illustrated in Figs. 8A-8I.

Figs. 9A-9B schematically show a pixel 100 comprising a flipper 24, in accordance with a preferred embodiment of the present invention. Referring to Fig. 9A, pixel 100, which is shown in a perspective view, is very similar to pixel 20. The only difference is in the construction of the brackets that couple flipper 24 to electrode 30. In pixel 20 flipper 24 is coupled to electrode 30 by U brackets 36 and 38 each of which has two legs that attach the U bracket to electrode 30. In pixel 100 flipper 24 is coupled to electrode 30 with brackets 102 and 104 each of which has a single leg 106 that attaches the bracket to electrode 30. Each of brackets 102 and 104 has a second leg 108 that does not extend all the way to electrode 30. There is a gap 110 between the end of leg 106 of each of brackets 102 and 104 and electrode 30. Gap 110 is best seen in a profile view of pixel 100 taken along a line B – B shown in Fig. 9A. Gap 110 is made small enough so that flipper 24 does not slip out or shake loose from brackets 102 and 104. Brackets 102 and 104 are smaller than brackets 36 and 38 because brackets 102 and 104 are anchored to central pixel 30 at one location whereas brackets 36 and 38 are anchored to central pixel 30 at two locations.

The decreased size of brackets 102 and 104 with respect to brackets 36 and 38 is advantageous. When surfaces of a pixel, in accordance with a preferred embodiment of the present invention, are treated to give the pixel a first and second color, e.g. black and white, the flipper of the pixel is turned to an on position, for example, and all exposed surfaces of the pixel are treated to give them the first color. The pixel flipper is then turned to the off position and all exposed surfaces of the pixel in the off position are treated so that they have the second color. Surfaces that are exposed in both the on and the off position of the flipper therefore have the second color. As a result, with the flipper is in the off position the pixel displays more of the second color than the pixel displays of the first color when the flipper is in the on position. This asymmetry is undesirable and surfaces of the pixel that are always exposed should be reduced to a minimum. Substantially all surfaces of brackets used to couple a flipper to a pixel

are exposed in both the on and off positions of the flipper and it is therefore advantageous to reduce the size of brackets that are used to couple a flipper to a pixel.

Figs. 10A-10B schematically show perspective views of another pixel 120 comprising a flipper 122, in accordance with a preferred embodiment of the present invention. Referring to Fig. 10B, flipper 122 has mounting holes 124 and an edge 126 having slots 128 that merge with mounting holes 124. Referring to Fig. 10A flipper 122 is coupled to central electrode 30 by preferably identical brackets 129 and 130. Bracket 130 is cut away in Fig 10A to show its construction. Each of brackets 129 and 130 comprises a septum 132 and a rim 134. Septa 132 of brackets 129 and 130 fit in slots 128 of flipper 122 and prevent movement of flipper 122 in a direction parallel to edge 126. Rims 134 of brackets 129 and 130 prevent flipper 122 from detaching from brackets 129 and 130.

As in the case of brackets 102 and 104 shown in Fig. 9A, preferably, each of brackets 129 and 130 is anchored to central electrode 30 at only one location. Preferably, one end of each of rims 134 is anchored to central electrode 30 and a small space 133 separates most of each septum 132 and each of the other end of a rim 134 from central electrode 30. Insert 135 in Fig 10A shows a schematic profile view of bracket 134 and central electrode 30 that illustrates the manner in which bracket 129 is attached to central electrode 30.

Fig. 11 schematically shows a perspective view of another pixel 140 comprising flipper 142, in accordance with a preferred embodiment of the present invention. Flipper 142 has protuberances 144 at opposite ends of edge 146 of the flipper. Protuberances 144 are held in socket brackets 148. Socket brackets 148 comprise a back panel 150 and a rim 152. Back panel 150 prevents flipper 142 from shifting laterally in a direction parallel to edge 146. Rims 152 prevent flipper 142 from separating from socket brackets 146. Each of brackets 148 is preferably anchored to central electrode 30 at one location by a "foot" 149, only one of which is shown in Fig. 11. A small space 151 separates most of the body of a bracket 148 from central electrode 30.

In an alternative design of socket brackets 146 socket brackets 148 comprise only rims 152. Rims 152 prevent flipper 142 from shifting laterally in a direction parallel to edge 146 as a result of contact of rims 150 with the short edges of flipper 142.

It should be noted that whereas pixels and flippers shown in Figs. 1A-11 are rectangular, pixels having shapes other than rectangular, in accordance with preferred embodiments of the present invention, are possible and can be advantageous. For example, pixels can be formed in accordance with preferred embodiments of the present invention in which the pixels are diamond shaped or hexagonal. A flipper for a diamond shaped pixel would

be triangular and cover half the area of the pixel. A flipper for an hexagonal shaped pixel would cover half the hexagonal area of the pixel.

Figs. 12A - 12K illustrate schematically a process for forming pixel 100 shown in Figs. 9A and 9B. Figs. 12A - 12K show cross-sectional views taken along a line A - A shown in Fig. 9A of a process for forming and etching layers required to produce pixel 100.

Production steps illustrated in profile in Figs 12A-12F are identical to steps in the production of pixel 20 shown in perspective views in Figs. 8A-8F respectively. In Fig. 12A insulating layer 23 is deposited on substrate 22. A layer 80, shown in Fig. 12B, of conducting material is then deposited on insulating layer 23. Layer 80 is etched to form first, second and central electrodes 26, 28 and 30 respectively which are shown in Fig. 12C. In Fig. 12D electrodes 26, 28 and 30 and exposed surfaces of insulating layer 23 are covered with sacrificial layer 82. Sacrificial layer 82 is covered with a layer 84 of conducting material, which is shown in Fig. 12E. Layer 84 is etched to produce flipper 24 shown in Fig. 12F. In the cross-section view shown in Fig. 12F and in Figs. 12G-12K that follow, flipper 24 appears to have two disconnected parts, an axle part 93 and a body part 91, however this is only an artifact of the choice of cross-sectional cut.

Following the etching of flipper 24, portions of sacrificial layer 82 are etched away as shown in Fig. 12G to lay bare regions 228 and 229 of central electrode 30. A relatively thin sacrificial layer 226 is then deposited on all exposed surfaces of pixel 100. Sacrificial layer 226 is then etched to uncover a small region 230, shown in Fig. 12I, of central electrode 30.. Sacrificial layer 226 serves to physically isolate axle part 93 (and body part 91) from a next conducting layer 232, shown in Fig 12J, that is deposited on pixel 100. Region 230 that is uncovered when sacrificial layer 226 is etched, serves as an area of central electrode 30 to which conducting layer 232 bonds strongly.

Conducting layer 232 is etched to form bracket 104 and all sacrificial layers are eroded away to form pixel 100 shown in Fig. 9K and also in Figs. 9A and 9B.

It should be noted that if sacrificial layer 226 is etched in region 229 in the same way that sacrificial layer 226 is etched in region 228 to expose region 230, conducting layer 232 would bond strongly to central electrode 30 in two places, one place on either side of axle part 93. A symmetric bracket anchored to central electrode 30 in two places similar in shape to bracket 38 shown in Fig. 8N could then be formed. A bracket formed in this way would however have shoulders similar to shoulders 99 of bracket 38 but with a height determined not by the thickness of sacrificial layer 82 but by the thickness of sacrificial layer 226.

As noted above, one possible function of nubs 44 and 45 is to reduce stiction. Some embodiments may not include nubs (which reduce the area of contact) or the nubs may not reduce stiction by a sufficient amount. The following description contemplates various methods of counteracting and/or avoiding stiction, in accordance with various preferred embodiments of the invention. However, it is noted that some embodiments of the invention will utilize more than one or none of the following described methods. It is expected that some combinations of methods will interact in a synergistic manner, drastically reducing stiction.

In a preferred embodiment of the invention, the flipper-pixels are encased in a sealed environment. This environment may include desiccant materials, as well as dry gasses, such as nitrogen. Alternatively, the flipper may move in a vacuum. In a preferred embodiment of the invention, the sealed environment comprises a flat layer of glass or another transparent material which is suspended over the flipper plane by a plurality of support elements protruding between the flippers, at the periphery of the display and/or replacing individual flippers. Preferably, groups of pixels or the whole display are in a single sealed cell.

Alternatively or additionally, one or more levitation electrodes are provided adjacent the flippers to assist in overcoming the stiction forces by applying an extra force beyond that applied by the plane electrodes.

Fig. 13A illustrates a pixel 300 including a levitation electrode 302, in accordance with a preferred embodiment of the invention. Except for electrode 302, Fig. 13A corresponds exactly to pixel 20 shown in Fig. 1A. The particular construction of electrode 302 shown in that of an open fence. However, other constructions, such as a solid construction or one in which the "bars" of the fence are not parallel to the pixel surface and/or the outer edge of flipper 24, can be used.

Fig. 13B is a sectional view along a line A-A of pixel 300, showing levitation electrode 302 and showing lines of an electric field generated by the levitation electrode and an optional corresponding electrode 304 on the other side of the flipper. As shown in the Fig., levitation electrode 302 exerts levitation forces perpendicular to flipper 24 and at its end, where they have a greater leverage for flipping the flipper and overcoming stiction. Once the flipper is levitated, these extra forces are not needed and can be shut off. In a typical configuration, these levitation forces will tend to obstruct the flipping, and, so, are preferably shut off so that they do not adversely affect the flipping. It should be noted that similar, albeit smaller, perpendicular forces can be achieved even if the electrode 302 is shorter, at the level of the flipper or even slightly below.

Fig. 13B shows an embodiment in which the levitation forces directly raise the flipper. However, in other preferred embodiments of the invention, other forces vectors can be used to overcome the stiction. In one example, the levitation forces may be used to move flipper 24 in the plane of the flipper, thereby breaking the flipper's adhesion to the substrate below it.

In the example of Fig. 13A, a particular levitation electrode is shown. However, in other preferred embodiments of the invention other electrode constructions can be used. Thus, as noted above, the electrodes can be solid or ribbed. In addition, the height of the electrode may vary, for example, the levitation electrode can be at the height of the flipper. In an exemplary embodiment, the electrode is 6 microns from the base of the flipper. Alternatively or additionally, the location of the electrode can vary. Thus, a levitation electrode may be situated along the outside edge of the flipper (as shown), along its side and/or at a corner of the flipper (near the outside edge or near the hinge).

Additionally or alternatively, an opening may be defined in the flipper and the levitation electrode placed in the opening. In one example, the flipper is slotted from the outside edge towards its middle and a levitation electrode protrudes through the slot. Alternatively or additionally, the levitation electrode may be suspended above the flipper, for example attached to an under surface of a transparent cover. In some embodiments, the levitation electrodes are wired together and work in concert, so that precise alignment of the levitation electrodes and the flipper-pixels is not required. Alternatively or additionally, the levitation electrode may be located at, adjacent or above the hinge area, for example to be symmetric with respect to the hinge.

Although a planar levitation electrode is shown, in some preferred embodiments of the invention, the electrode can be non-planar, for example being columnar. Alternatively or additionally, the electrode may border the flipper on two or three sides.

Another parameter of the electrode which may be controlled is its length (along the length of the pixel edge - opposite the hinge). Although an electrode which is as long as the flipper is shown, shorter electrodes may be provided, for example, electrodes between 30% and 80% of the dimension of the flipper.

Another parameter which may be controlled is the symmetry of placement of the electrode relative to the flipper shape, the flipper hinge and other levitation electrodes. In some cases it is desirable that the force lines be generated in a certain direction which is oblique to the flipper motion. Alternatively or additionally, non-symmetrical positioning may be used to reduce the effects of levitation electrodes of one pixel on another pixel. Alternatively or additionally to the position being asymmetrical, the size and/or shape of single electrodes may

also be asymmetric. Also the activation (voltage, timing) of the electrodes (for example as described below) may be different for different electrodes and/or pixels.

In Fig. 13B, two levitation electrodes are shown, one on each side of the pixel. In some preferred embodiments of the invention, levitation electrodes are shared between pixels. In embodiments where only a single levitation electrode is used per pixel, a possible arrangement is to alternate levitation electrodes every other pixel. If corner levitation electrodes are used a saving of a factor of two or four in the number of levitation electrodes can be achieved. It is noted that a line or other grouping of levitation electrodes may be wired together to be activated simultaneously.

In some preferred embodiments of the invention, a different levitation electrode is electrified (or a different electrification profile is used), depending on the type of flipper movement, e.g., left, right and/or speed. Alternatively, a same electrification may be used for different flipper movements, for example if the electrode is alongside the side of the flipper (perpendicular to the hinge), rather than its edge, any electrification of the electrode will cause the flipper to levitate, thereby breaking the stiction.

In some preferred embodiments of the invention, several electrodes are operated in concert in order to overcome the stiction, for example as shown in Fig. 13B.

A levitation electrode may, in some preferred embodiments of the invention, comprises a plurality of sub-electrodes, which may be arranged, for example, vertically or horizontally. The sub-electrodes may be electrified in parallel or in series. Alternatively or additionally, the sub-electrodes may be electrified with different voltages.

In a preferred embodiment of the invention, the voltage on the levitation electrode is varied during its application, preferably, using a timing circuit. One possible type of variation is to modify the voltage as a function of the expected position of the flipper. For example, as the flipper moves, the voltage is reduced (e.g., until it is zero). Alternatively, different electrodes or parts of the electrode are electrified as a function of the flipper position. Alternatively or additionally, the electrification is modified as a function of the stiction forces, which can be measured in a laboratory, for example, for setting the timing circuit. Alternatively or additionally, the electrification is varied responsive to the flipping speed, for example a higher voltage being used if higher flipping rates are required. The variation in voltage may be continuous or it may be stepped, for example depending on the control electronics used.

In some preferred embodiments of the invention, the timing of levitation electrodes is synchronized with the flipping of flippers. In one example, the levitation electrodes are activated to break stiction prior to activating the flipping electrodes. The amount of force

provided may be only sufficient to break the stiction or it may be enough to actually lift the flipper a certain amount. Alternatively, the levitation electrode and flipping electrodes have an overlapping activation, to apply a maximum force against stiction. In some embodiments the levitation electrode is used to cause vibrations or otherwise flexing of the flipper and/or associated structures. In these embodiments, the levitation electrodes may be activated before the flipping electrodes, which are activated in a manner timed to utilize the effect of the levitation electrodes.

In some preferred embodiments of the invention, levitation electrodes may be activated to break stiction on a plurality of pixels (or the entire device) simultaneously, with the flipping electrodes being activated only for selected ones of the pixels.

In some preferred embodiments of the invention, different amounts of force are applied by different levitation electrodes and/or flipping electrodes for different pixels. This reflects differences in stiction and/or friction for different flippers.

The above description has focused on using a levitation electrode for a flipping-type pixel. However, it should be noted that such levitation electrodes may also be advantageously used in other pixel types, for example as described in the prior art or even in the instant pixels in scales larger than one millimeter square. Thus, in general, a levitation electrode breaks the stiction and a functional electrode causes the element to change state. Additionally, a stiction counter-acting electrode may be used in other MEMS devices, for example to assist in the initiation of the motion of rotors or other moving, bending or flexing elements which adhere to the substrate or other micro-mechanical structures. Such elements may be smaller (in their maximum dimension) than 5 millimeters, 1 millimeter, 0.1 millimeter, 0.01 millimeter or even 0.005 millimeters, depending on the application. Alternatively, larger elements are provided. Thus, a stiction-countering electrode may be used in a electrostatic motor or to loosen up a beam-type sensor.

Figs. 14A-14F, which correspond to some of figures 8C-8M, illustrate steps in manufacturing a pixel, having levitation electrodes, in accordance with a preferred embodiment of the invention. This method is only exemplary and many other manufacturing methods and variations thereof will occur to a person skilled in the art.

Fig. 14A corresponds to Fig. 8C and shows a pixel 310 having two electrode bases 312 formed along with electrodes 28, 30 and 26.

Fig. 14B corresponds to Fig. 8D and shows anchor vias 314 formed along side vias 81 and 83 for allowing an upper electrode layer formed later to contact electrode bases 312.

Fig. 14C corresponds to Fig. 8F and shows second electrode portions 316 formed above layer 82 and in a same plane as flipper 24. It should be noted that electrode portions 316 contact electrodes bases 312 through vias 314.

Fig. 14D is a side view of Fig. 14C, showing only the electrodes, in which layer 82 is transparent, showing the bridging of electrode layers 312 and 316 through vias 314.

Fig. 14E is a rendering of Fig. 14C, in which layer 82 is transparent, showing the double levitation electrode structure.

Fig. 14F corresponds to Fig. 8M and shows the final structure, in which three electrode layers are deposited, including a top electrode portion 318.

As shown in Fig. 14F, the levitation electrodes may be designed to have a minimal shadowing effect on pixel 300, by being low, narrow and perforated. In other embodiments, only one of these features is used. Alternatively or additionally, the levitation electrodes may be made reflecting, to reflect the surface color of the adjacent flipper and/or substrate. Alternatively or additionally, transparent levitation electrodes are used. In the embodiments where the electrodes are formed above the flipper, they may be comprised of transparent conductive polymer deposited on a transparent cover.

In a preferred embodiment of the invention, the amount of stiction between a flipper and a substrate is reduced by providing electrically insulating nubs between them, to reduce the area of stiction. This and other techniques described below may also be provided using nubs on the flipper instead of or in addition to nubs on the substrate, on the same side of the flipper or possibly one type of bump on either side of the flipper. Alternatively or additionally, a low stiction coating is used between the flipper and the substrate. In a preferred embodiment of the invention, the coating also servers a visual function, for example providing a reflective (e.g., white) or an absorbent area, in black and white and/or in color. One particular example is Silicon Nitride, which, depending on the thickness of the layer, is either reflecting or absorbing. The coating may be applied over nubs 44 (Fig. 8M) or underneath them. Alternatively to Silicon Nitride, other materials or groups of materials may be used to provide the dual insulation-color functions. Other materials may also be selected, for example based on having the property of varying their optical characteristics based on chemical and/or physical variations in the material and/or its crystal structure. Silicon Nitride coating is described, for example in "Fabrication of Micromechanical Device for Polysilicon Films with Smooth Surfaces", by Guckel, in Sensors and Actuators 20 (1989) 117-122, the disclosure of which is incorporated herein by reference.

Alternatively or additionally, such materials may also be used to coat the hinge (38 in Fig. 8M), to reduce stiction and/or friction. Alternatively or additionally, surface area reducing techniques, as described below for nubs may also be applied to the hinge.

In a preferred embodiment of the invention, the tips of nubs 44 (Fig. 8M) are manufactured to have a minimal sized contact area with the flipper, for example using an isotropic etch to make them small, as described for example in "Stiction in Surface Micromachining", by Tas, in J. Micromech. Microeng. 6 (1996) 385-397, the disclosure of which is incorporated herein by reference.

Alternatively or additionally, to making the nubs small, the nubs may be pitted (e.g., have one or more cavities formed at their top), further reducing the contact area.

Figs. 15A-15E illustrate an exemplary method of manufacturing a pitted nub, in accordance with a preferred embodiment of the invention. In Fig. 15A a silicon substrate 330 is provided, coated with a nitride layer 331 and an electrode layer 332, such as for electrode 24. A sacrificial oxide layer 334 is formed on the electrode, with a via 335 therein.

In Fig. 15B, a poly-silicon layer 336 is formed which fills via 335.

In Fig. 15C, layer 336 is patterned to remove it except in the vicinity of via 335.

In Fig. 15D, layer 336 is etched to remove it down to the level of layer 334 or even slightly below. This removal is preferably achieved using an isotropic wet etch, although other methods known in the art may be used.

In Fig. 15E, layer 336 is further etched to form a pit 383 in the top of a formed nub 340. Thereafter, a layer of Silicon Nitride may be deposited.

Preferably, but not necessarily, the nubs are formed closer to, rather than further from hinge 38, to allow a greater leverage for levitation electrodes and flipping electrodes against stiction. Alternatively, in some embodiments, the nubs may be formed far from the hinge to allow the flipper to sag and/or vibrate.

Figs. 15F-15G illustrate an alternative method of forming a rounded nub, in accordance with a preferred embodiment of the invention. In Fig. 15F, a nitride layer 331 is deposited n a silicon substrate 330. A polysilicon layer 342 is deposited and then a photoresist layer 344 is deposited above. It should be noted that in this and other embodiments, other materials than polysilicon may be used, for example oxide or other materials known in the art. The photo-resist layer is patterned, as shown in the Fig. and then an isotropic etch is used to undercut polysilicon 342 (or other materials used) underneath, forming a narrow nub-stub (shown dotted as element 343). Then, in Fig. 15G, a layer of polysilicon 346 is deposited for the electrodes, and, coating the nub-stub, a small-tip nub is formed, which tip is smaller than the process

dimensions. Thereafter, a layer of nitride is preferably deposited. One possible advantage of this construction is that the nub is symmetrical on both sides. Another possible advantage is that pitting is not required.

Alternatively or additionally, active methods of reducing stiction may be used. one active method is to vibrate the flipper and/or other associated pixel structures so that stiction is broken or at least so that during the vibration stiction is reduced sufficiently for levitation electrodes or flipping electrodes to break the stiction. This may require timing the electrification of these electrodes to the modes of the vibration. However, it may not be required in all embodiments.

The induced vibration may include a component in the direction of flipper motion or it may be wholly perpendicular to the flipper motion. The effected vibration, however, even though coupled to the induced vibration, may have a component in the direction of the flipper motion.

In a preferred embodiment of the invention, the vibration is generated by electrifying electrodes in a periodic or other manner to induce the vibrations, for example, the levitation electrodes (or the flipping electrodes) may be switched on and off at a resonance frequency of the flipper (or other pixel structures), thereby increasing the vibration amplitude until the stiction is broken. This vibration may be combined with DC forces. Alternatively, special vibration causing elements may be provided to generate the vibratory motions. Possibly, the vibration of the flipper is a side effect of the flipping of the current or other flippers, so that the flipper are usually vibrating. Optionally, the device is constructed with a reduced inter-pixel damping, so that vibration of one flipper is coupled to vibration of other flippers. Alternatively, damping is provided to decouple the flippers.

The vibrations may be locally generated, for example, by providing a piezoelectric material associated with a pixel or groups of pixels. Alternatively, as shown in Fig. 16, remote generation of vibrations, by a single or a few sources, is utilized.

Fig. 16 illustrates a display device 350 on a substrate 351 including a vibration generator 352, in accordance with a preferred embodiment of the invention. In this exemplary embodiment, flippers in a display area 360 are excited by a piezoelectric material 356 sandwiched between an electrode 354 and an electrode 358 at a periphery of the display device. The vibrations are preferably only activated at the start of a flipping cycle. However, if desired they may be activated continuously.

In a preferred embodiment of the invention, the pixel element which is vibrated is the flipper. In some cases, the flipper may be made of a suitable flexible material. Alternatively, a

plurality of apertures may be formed in the flipper or the flipper made hollow, to support such flexing. In a preferred embodiment of the invention, energy storage in the flipper is provided using one or more springs attached to the flipper and preferably formed integral with the flipper.

Figs. 17A and 17B illustrate a flipper 370 with integral springs 372 in a top view and a side view thereof, in accordance with a preferred embodiment of the invention. In Fig. 17A a pair of nubs 374 are shown near the hinge, to enhance the flexing of the flipper. Although two springs are shown, one at each outside corner, the springs may be formed along any part of the edge of the flipper, or even in the middle of the flipper, if they extend beyond the flipper plane. Additionally, other numbers of springs may be used, for example one or three. In Fig. 17B the springs are shown as being formed by extensions of the sheathing of flipper 370 without an internal support. In a preferred embodiment of the invention, the sheathing is formed of Silicon Nitride.

Figs. 17C and 17D illustrate steps in manufacturing an integral flipper spring 372 in accordance with a preferred embodiment of the invention. A poly-silicon layer 380 is sandwiched between a nitride layer 376 and a nitride layer 378. Then the flipper is covered with a photo resist layer and a hole is formed in the photo resist layer adjacent spring 372. A wet etch may then be used to etch poly-silicon layer 380 underneath nitride layer 376 while the photo resist layer protects the rest of the pixels from the etching Fig. 17D shows the resulting springs in which layer 380 is etched away in spring 372.

In a preferred embodiment of the invention, the spring are used to enhance the effects of vibration, for example amplitude, energy storage, and/or coupling of vibration modes. Alternatively or additionally, the nubs may be formed to enhance the transfer of vibration, especially increasing the vibration amplitude, to the flipper. In some embodiments, the flipper must flex in order to be in contact with both the nubs and the springs, against the substrate.

In some preferred embodiments of the invention, a touch input device is associated with the flipper-pixels. In a preferred embodiment of the invention, the touch sensitive area is above the flippers, so that the display functions as a touch screen. Alternatively, the flippers may be used to generate a display for other types of touch input devices, such as touch-pads. Although the area contacted by a finger is generally above the flippers, in some embodiments, at least some of the electronics and/or sensors associated with acquiring the touch input are at or below the flippers.

In a preferred embodiment of the invention, the resolution of the touch input is lower than that of the display, however, this is not essential. Preferably, the spatial resolution is

uniform. However, in some embodiments, non-uniform spatial touch resolution may be provided. Various types of input technologies may be used, including, but not limited to capacitance based sensing, resistance based sensing, and SAW (surface acoustic wave) based sensing.

Fig. 18A is a schematic circuit diagram for a passive type touch input device 400, in which a touch position is detected by a switch or a sensor at a touched location. A plurality of row electrodes 404 (formed in the substrate) cross a plurality of column electrodes 402 similarly formed on the substrate at a plurality of switches 406. When a switch is closed, for example as a result of pressure on the touch screen, the relevant row and column electrodes are shorted (or the resistance between them lowered) and this shorting can be detected using standard circuitry at the periphery of the device. Alternatively, other types of pressure detection and/or switch closure detection circuitry may be used.

Fig. 18B is a schematic side view of device 400, showing a plurality of support elements 408 which space a transparent cover 410 from switches 406. When pressure is applied top cover 410, as shown for example by a reference 414, support element 408 is pushed down, thereby urging a row electrode 404 against a column electrode 402. Flipper pixels can be disposed in areas 412 between the support columns. In a preferred embodiment of the invention, row electrode 404 is suspended over column electrode 402 (or vice-versa) using a double suspension beam, connected to the substrate on either side of the column electrode. Although switches 406 are shown as forming protrusions in the device surface (e.g., of the flipping electrodes), this is not essential and they can be flush, for example being formed in depressions.

Support elements 408 may be separate elements deposited onto of the row electrodes (possibly with an intervening insulation layer) or they may be attached to cover 410.

In one preferred embodiment of the invention, a switch 406 is formed at a lower spatial resolution than the flipper, for example one switch every 50 linear pixels. Thus, some pixels may be replaced by switches. Alternatively, the switches (and support elements) are formed between pixels, or by reducing the sizes of neighboring pixels rather than removing them entirely. Alternatively, they may be larger than a pixel.

In some preferred embodiments of the invention, a standard pixel may be created, which pixel is suitable for both flipping and touch detection. When a support element is deposited or otherwise attached over the pixel, that pixel serves as a switch 406, otherwise, the pixel remains a flippable pixel.

Although passive addressing may be used for addressing an array of flipper-pixels, in some preferred embodiments of the invention, active addressing methods are used. In some preferred embodiments of the invention, circuitry at each pixel is used to amplify the power and/or extend the duration of the flipping activity to power level or durations greater than that of data transmission to the pixel. Thus, data can be written to the pixels at a high rate, substantially independently of the actual pixel flip rate.

Fig. 19 is a schematic circuit diagram of a circuit for driving a flipper-pixel, in accordance with a preferred embodiment of the invention. In a preferred embodiment of the invention, this circuitry is implemented as a thin film, for example as used in thin film transistors, deposited under the flipper pixels, however, this is not essential. This circuit can be used to translate column and row driving signals into an activation of the flipper. A similar circuit may be used to activate the levitation electrodes, if any. In an exemplary method of using this circuit the following logic is used (and implemented using the circuitry shown and/or other driving and device control circuitry):

(a) a word line is selected and all the data lines (for a row) are brought to an appropriate potential (when left is selected, right is grounded and vice-versa);

(b) the data lines potentials cause one capacitor in each pixel to be charged, which charging turns on a thin film transistor (TFT);

(c) the activated thin film transistor connects the middle electrode to the appropriate voltage, or ground, based on which capacitor was charged;

(d) the word line is grounded so that the pixel control circuit is disconnected from the peripheral control; and

(e) the middle electrode stays at that voltage until the capacitor discharges below the TFT on voltage. Although line scanning is described, individual pixel scanning and other scanning methods known in the art may be used.

In a preferred embodiment of the invention, the circuitry, for example as shown in Fig. 19, is deposited under the flippers. The flippers can be manufactured using aluminum on glass technology, which is, in some variations thereof, similar to silicon processes, except that aluminum is used instead of polysilicon as a conductor and a polymer is used as the sacrificial layers. In other embodiments, other micromachining technologies may be used for constructing a device in accordance with a preferred embodiment of the invention.

Alternatively or additionally, circuitry for the display as a whole (e.g., peripheral-area circuitry) may be provided using flip-chip bonding techniques. Thus, integrated circuits can be attached to the face of the display device. Fig. 20 illustrates an exemplary device 500 in which

a pixel area 502 is connected by a plurality of lines 506 to driving circuitry. In the figure, one set of lines are shown connected to a chip 510, while a second set of lines are shown as terminating at flip-chip bump-pads 508, which a flip-chip containing driving circuitry can be attached to. Alternatively to flip chip bonding, wire bonding may be used.

In passive addressing, it is usually desired that a pixel has a step-like response to voltage, so that selectivity of the pixels to be flipped will be high. In some preferred embodiments of the invention, stiction is used to provide such a step response. In one example, the combination of levitation electrodes and flipping electrodes is required to flip a pixel, the electrodes being activated in series or in parallel. Alternatively or additionally, other stiction reduction methods, such as vibration may be used.

In some preferred embodiments of the invention, separate sets of row and column electrodes are provided for flipping and levitation uses. Alternatively, the levitation electrodes may be electrified as groups or as a single unit for the whole display.

The above devices may be manufactured using many different technologies. However, In a preferred embodiment of the invention, the pixels are manufactured using aluminum on glass technology. It should be noted that by using non-silicon substrates, larger display devices may be achieved. Further, by using flexible substrates, flexible display devices can be manufactured. Possibly, each pixel is stiffened, for example by depositing metal or silicon layers, so that the display device bends between pixels rather than at pixels.

In the description and claims of the present application, each of the verbs, "comprise" "include" and "has", and conjugates thereof, are used to indicate that the object or objects of the verb are not necessarily a complete listing of components, elements or parts of the subject or subjects of the verb.

The present invention has been described using non-limiting detailed descriptions of preferred embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. Variations of embodiments described will occur to persons of the art. For example, a pixel in accordance with a preferred embodiment of the present invention may comprise different combinations of features and elements of the preferred embodiments of the present invention described above. In some preferred embodiments of the present invention, a pixel might omit features and/or elements comprised in the described preferred embodiments. In other pixels in accordance with a preferred embodiment of the present invention, features and/or elements shown only in different ones of the described preferred embodiments may be combined. The scope of the invention is limited only by the following claims.